Deltares

Maasvlakte site evaluation

Cooling water availability

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Client	Ministerie van Economische Zaken en Klimaat
Contact	
Reference	
Keywords	

Document control	
Version	1.0
Date	19-03-2026
Project nr.	11209639-002
Document ID	11209639-002-GEO-0006
Pages	123
Classification	
Status	Final

Summary

The Dutch government is considering developing two new large nuclear power plants in the Netherlands and has selected nine possible sites at Sloegebied (Borssele), Terneuzen, Eemshaven and the 2e Maasvlakte as potential locations for this. Similar to Borssele, Deltares was requested by The Ministry of Economic Affairs and Climate Policy (EZK) to perform, amongst others, a detailed modelling study on the availability of cooling water at the Maasvlakte. This will provide initial technical information to possible vendors (i.e., developers) which need to carry out their own technical studies towards an initial design of such a plant.

The objective of this cooling water study is to assess the cooling water availability/capacity in the Maasvlakte area. Specifically, assess the plume dispersion and recirculation of the new Maasvlakte cooling water discharge in relation to the applicable environmental criteria for different intake and outfall options (Deltares, 2023). This study aims to provide developers with an initial indication of the feasibility of investigated cooling water configurations based on temperature criteria. The studies carried out are not intended to be complete and are therefore not a guarantee that, if the developers follow the information provided, this will entitle them to a permit and acceptance of the development. It is further noted that the authorities have indicated that water quality and ecology are also important aspects in relation to the feasibility of the development of nuclear power plants and that these aspects have not yet been included in this first, exploratory study.

The available information for the Maasvlakte project site was inventoried and presented. This inventory includes descriptions and analyses of the bathymetry, environmental criteria and relevant ambient conditions at the project site. A complete overview of the environmental criteria for the Maasvlakte 2 intake and outfall configuration is presented in the 'Brief regelgevend kader Maasvlakte', Deltares (2024). Together with EZK, potential Maasvlakte intake and outfall designs, discharge characteristics and discharge options were identified and agreed to be simulated.

To assess the plume dispersion and recirculation of discharged cooling water in the Maasvlakte area, a detailed far field model was set up in Delft3D. This far field model simulates the important hydrodynamic processes for the plume dispersion and heat exchange with the atmosphere with sufficient horizontal and vertical resolution. Hydrodynamic boundary conditions were derived from in-house available and validated overall models of the Rijn Meuse estuary model. Model results from the detailed model were compared to the overall model for verification. For design options that consider a submerged outfall, the near-field behaviour of the submerged outfall thermal plume was assessed by means of the CORMIX expert system. CORMIX computes the hydrodynamic behaviour of the outfall plume close the outfall including the plume trajectory and dilution under influence of the ambient conditions. The results of the near field assessment were subsequently coupled to the far field model with use of Deltares' C-SUMO (Coupled Subgrid Model) system.

With the coupled Delft3D-FLOW model and near-field results of CORMIX, different simulations were performed for representative scenarios (i.e. different intake and outfall configurations, locations, different thermal discharge capacities, discharge characteristics and additional structures/breakwaters). The modelling results were subsequently analysed and presented in relation to the environmental (thermal) criteria.

Based on the available information and modelling results, the following main conclusions are drawn:

- For the present first assessment of different Maasvlakte cooling water configurations only the CIW 2004 (temperature) mixing zone and average temperature increase (at the estuary area) criteria were used. It is noted that compliance with possible other criteria (e.g., on other water parameters) would need to be evaluated in a full environmental impact assessment study in a next phase of the project.
- No detailed designs or discharge characteristics were available at the start of this assessment. Therefore, together with EZK, different cooling water discharge characteristics and intake and outfall options for the Maasvlakte plant were selected to be assessed in the present modelling study.
- The existing intake and outfalls are not implemented in this modelling study due to unavailability of data. Therefore, only the new development is assessed, which follows the objective of the study. It is noted however that the operation of existing intakes and outfalls could have an effect on the operation and possibly feasibility of the intake and outfall configurations for the nuclear power plant assessed in this study and in a next phase of the project, these should be considered. For the present initial phase of the project, the assessment without the existing operations is nevertheless deemed representative.
- For the present modelling assessment on the Maasvlakte cooling water system, 7 different intake and outfall configurations were considered. These configurations include variations in the location of the intake and outfall, the type of intake and outfall structure (open or submerged) and additional structures (breakwaters). Furthermore, variations in the thermal discharge capacity and discharge characteristics were simulated. An overview of the simulated scenarios is presented in the below table.

Table S.1 Overview of simulated scenarios.

Scenario	**Thermal Capacity (MW_{th})**	**Discharge option/Cooling water Temperature increase**	**Intake/Outfall Location Configuration**	**Additional structures**	**Description**
0	-	-	-	-	Present situation
1	6000	2/+9°C	1	-	Open outfall at the North side, open intake in the Harbour side.
2	4000	2/+9°C	1	-	Open outfall at the North side, open intake in the Harbour side.
3	6000	1/+7°C	1	-	Open outfall at the North side, open intake in the Harbour side.
4	6000	3/+12°C	1	-	Open outfall at the North side, open intake in the Harbour side.
5	6000	2/+9°C	2	-	Submerged outfall at the North Side, open intake at the Harbour side.

Scenario	Thermal Capacity (MW_{th})	Discharge option/Cooling water Temperature increase	Intake/Outfall Location Configuration	Additional structures	Description
5b	6000	3/+12°C	2	-	Submerged outfall at the North Side, open intake at the Harbour side.
6	6000	2/+9°C	3	-	Open outfall at the West side, open intake at the Harbour side.
7	6000	2/+9°C	4	-	Open outfall at the Harbour side, open intake at the North side.
8	6000	2/+9°C	5	-	Open outfall and open intake at the West side.
9	6000	2/+9°C	6	-	Submerged outfall and open intake at the West side.
9b	6000	3/+12°C	6	-	Submerged outfall and open intake at the West side.
10	6000	2/+9°C	1	-	Open outfall at the North side, open intake in the Harbour side. Different boundary conditions for salinity.
11	6000	2/+9°C	1	-	Open outfall at the North side, open intake in the Harbour side. Different boundary conditions for salinity.
12	6000	2/+10°C	1	-	Open outfall at the North side, open intake in the Harbour side. Sensitivity test effect existing operations.
13	6000	2/+11°C	1	-	Open outfall at the North side, open intake in the Harbour side. Sensitivity test

Scenario	Thermal Capacity (MW_{th})	Discharge option/Cooling water Temperature increase	Intake/Outfall Location Configuration	Additional structures	Description
					effect existing operations.
14	6000	3/+12°C	1b	Breakwaters	Open outfall at the North side, open intake in the Harbour side.

- The model results were compared to the applicable CIW 2004 thermal environmental criteria. For the Maasvlakte estuary area, the mixing zone is defined by the 25°C temperature contour. The maximum mixing zone should be less than 25% of the cross section of the water way. For the North Sea, the mixing zone (i.e., the 25°C contour) should not reach the seabed. Furthermore, the average temperature of the water body may not increase by more than 2°C and/or increase above 25°C.
  It is noted that only thermal criteria were assessed in this initial study and no other, possibly applicable criteria related to e.g., ecology (as part of the KRW guidelines) were assessed in this study. These need to be considered in a next phase of the project.
- The present modelling study has shown that all modelled cases result in limited average temperature increase at the estuary area. The average temperature increase due to the outfall discharge is less than the +2 °C criterion.
- All open outfall options will result in high temperature increase near the bed at the first hundred meters from the discharge location. Due to high discharge flow rates in combination with the limited local depths, the results show that there is limited initial mixing on the first tens of meters and a high temperature increase, up to 10°C, compared to background temperatures near the bed. Further away, up to hundred meters from the discharge location, the outfall plume stratifies and rises to the surface.
- For Configuration 1 and all discharge cases, the 2 °C excess temperature contour (i.e., 25 °C contour) touches the bottom over a length of about 100m. Further to the east of the discharge location and close to the coast, the temperature increase near the bed by 2 °C extends to a maximum distance of 350m from the coastline.
- Placing the outfall in the harbour area, e.g., Configuration 4, will result in an initially vertically mixed plume with a high temperature increase. Due to the confined area in the harbour and the limited flow circulation, the entire cross-sectional area at the outfall in the harbour increases temperature with 2 °C or more.
- For an outfall at the west side of the Maasvlakte area (e.g., Configuration 5), the 2 °C excess temperature contour can reach the bottom at a distance of 350 m from the outfall due to the shallow depths along the shore.
- To reduce the increase in (bottom) temperatures around the outfall, a submerged outfall diffuser is considered.
- A submerged outfall diffuser option showed that the discharged cooling water with the ambient water mixes rapidly over the water column. The results showed that such submerged outfall diffuser can prevent temperatures near the bed to increase above 25 °C (i.e., +2 °C) for several configurations, but that with higher cooling water temperatures (i.e., different discharge options), near-bed temperatures could still be high. It is therefore advised to carefully assess the outfall location and diffuser layout in more detail when a higher discharge temperature is considered.
- The results of these studies (and follow-up studies by the developers) must be compared with and, if necessary, adapted to the data from the KNMI's updated climate scenarios of October 2023.
- The mean temperature increase (i.e., recirculation due to the discharged cooling water) at the different intake location options is computed to be less than +0.1 °C for all

configurations, i.e., very limited. The exception is the configuration with an open outfall and open intake at the west side (Configuration 5), which reaches a mean recirculation of +1.2 °C (and a maximum recirculation of more than +4 °C).

Contents

1 Introduction

1.1 Project background

The Dutch government is considering developing two new large nuclear power plants in the Netherlands and has selected nine possible sites at Sloegebied (Borssele), Terneuzen, Eemshaven and the 2e Maasvlakte as the potential locations for this. For the government to make a decision to proceed with this development, possible vendors (i.e., developers) need to carry out their own technical studies towards an initial design of such a plant, including all hazard and safety considerations. EZK wants to provide these vendors with initial technical information for them to base their studies on.

Deltares received a request from EZK to perform a detailed modelling study on the availability of the cooling water capacity at Maasvlakte, in addition to the cooling water study at Borssele area. This initial feasibility study will inform EZK on the feasibility of this alternative location for the development of new nuclear power plants from a cooling water point of view and could form input to further technical feasibility studies or the environmental impact analysis. This study considers different scenarios and possible options for the intake and outfall of the cooling water system, but no specific design.

Figure 1.1 Project site (Maasvlakte).

Access to sufficient cooling capacity is crucial for the proper and safe operation of the new nuclear power plant. It is therefore important to assess the availability and access to sufficient cooling water both from an operational point of view, as well as from an environmental impact point of view, for the different locations under consideration for the new plant. To assist in these considerations and as input to environmental considerations, Deltares caried out a numerical modelling study to make a first assessment on the availability (capacity) of cooling water and possible options for the cooling water intake and outfall for the new plant.

1.2 Objectives

The objective of this cooling water study for a possible nuclear power plant (NPP) at the Maasvlakte II location is to assess the cooling water availability/capacity in the Maasvlakte area. Specifically:

- Assess the plume dispersion of the new Maasvlakte NPP cooling water discharge in relation to the applicable environmental temperature criteria for different cooling water intake and outfall options.
- Assess the recirculation potential of different Maasvlakte NPP intake and outfall options (i.e., the temperature increase at the Maasvlakte NPP intake).

This study aims to provide developers with an initial indication of the feasibility of investigated cooling water configurations based on temperature criteria. The studies carried out are not intended to be complete and are therefore not a guarantee that if the developers follow the information provided, this will entitle them to a permit and acceptance of the development. It is further noted that the authorities have indicated that water quality and ecology are also important aspects in relation to the feasibility of the development of nuclear power plants and that these aspects have not yet been included in this first, exploratory study.

1.3 Scope of work

The objective was studied by means of a numerical hydrodynamic model that simulates the dispersion of the discharged cooling water . This (detailed) model was set up around the Maasvlakte area and nested in the in-house available Rijn-Maas Monding (RMM3D) model. To accurately model the outfall plume, this detailed model was run in three-dimensional mode and with a sufficiently high model grid resolution.

With the model, different plant capacities, discharge characteristics, and intake and outfall configurations and structures were simulated under different ambient conditions. The intake and outfall configurations were agreed with EZK and the ambient conditions scenarios were based on the applicable environmental criteria and forcings that affect the plume dispersion. Model results were subsequently analysed and presented in relation to the environmental temperature criteria.

1.4 Reader

The report starts with the project information available to the present study in Chapter 2. Data on the bathymetry, intake and outfall design options and environmental criteria etc. are inventoried here. Chapter 3 describes the setup of the Delft3D hydrodynamic model. The results of the plume dispersion and recirculation modelling are described in Chapter 4 and Chapter 5 presents the conclusions of this study.

2 Project information

In this chapter, the available information relevant to the plume dispersion and recirculation of the Maasvlakte nuclear power plant is inventoried and presented. This inventory includes descriptions and analysis of the bathymetry, environmental criteria, ambient conditions at the project site, considered intake and outfall characteristics and discharge options.

2.1 Bathymetry

The latest available bathymetry data was obtained from the Overall model (Rhine-Meuse estuary model (RMM), see Section 3.1) which represents the RWS Baseline data of the 2022-year conditions. This bathymetry data covers the full domain of the detailed numerical model (see Section 3.2.2). The data has a horizontal coordinate system Amersfoort / RD new (EPSG code 28992) and referenced in the vertical to NAP. The data is presented in Figure 2.1. For presentation purposes the data is presented in the WGS 84 (latitude/longitude) coordinate system.

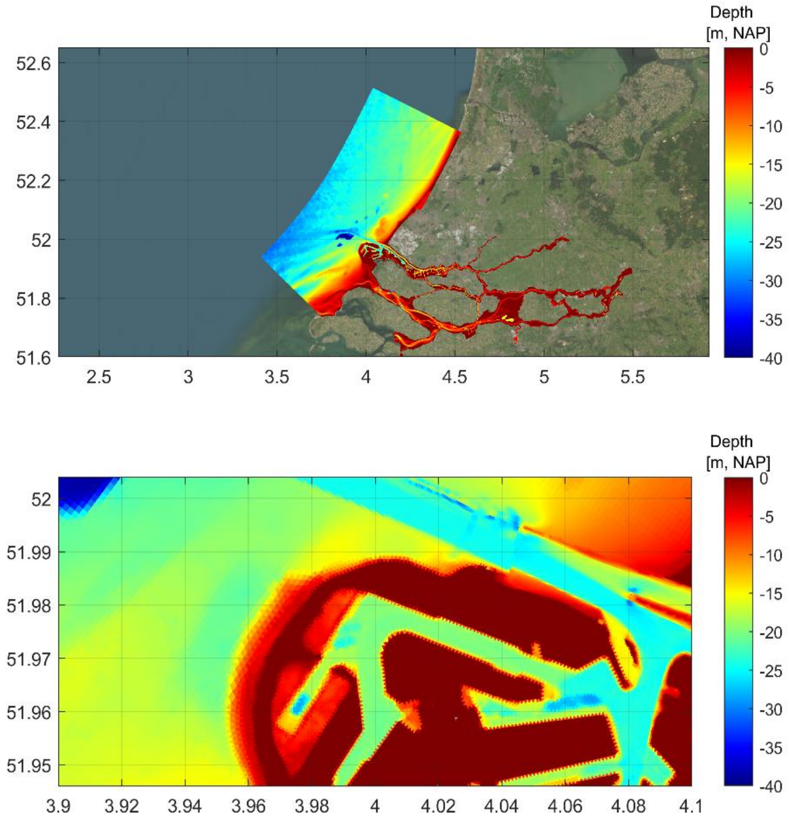

Figure 2.1 The bathymetry data of the Overall RMM model.

This dataset shows the bathymetry at the North Sea and the estuary area of the Maasvlakte. The depths close to the Maasvlakte area are relatively shallow. Along the coastline of the Maasvlakte area the depths are typically up to -10 m NAP. In the west side of the Maasvlakte area, the shallow depths are extended further offshore than the northern side area. In the Maasvlakte harbour basins, the depths are primarily around -20 m NAP. A dredged channel of about -25 m NAP connects the North Sea with the estuary entrance.

2.2 Environmental criteria

The Maasvlakte intake and outfall configuration and cooling water discharge need to comply with environmental temperature criteria in place. In the present assessment focus is on the temperature criteria that can be evaluated by means of numerical modelling. These environmental criteria include the CIW 2004 (Rijkswaterstaat 2004) criteria for thermal discharges. In summary, these criteria state:

- **Mixing zone.** For the Maasvlakte estuary area, the mixing zone is defined by the 25°C temperature contour. The maximum mixing zone should be less than 25% of the cross section of the water way. For the North Sea, the mixing zone (i.e., the 25°C contour) should not reach the seabed.
- **Average temperature increase**. The average temperature of the water body may not increase by more than 2°C and/or increase above 25°C.

Eventually, in a next phase of the project, a full environmental impact assessment will be needed that also includes an assessment of the impact on water quality and ecology. Compliance of the cooling water system with the CIW 2004 criteria is only a part of this environmental impact assessment. A full environmental impact assessment, or assessment against other criteria than temperature criteria, is not part of the present scope of work for this preliminary cooling water study.

Recirculation criteria

No recirculation criteria are available for het present assessment. The simulated recirculation potential at each intake will be presented such that it allows for independent further use.

2.3 Ambient water temperature

Application of the environmental criteria requires quantification of the ambient (background) water temperature near the project site. The background temperature is defined in the CIW 2004 criteria as the temperature at the edge of the water body. Water temperature data was downloaded from the water info data portal (www.waterinfo.rws.nl) and analysed to derive the 98^{th}-percentile water temperature (as per the CIW criteria, (Rijkswaterstaat, 2004)). The results are summarised in Table 2.1. Figure 2.2 and Figure 2.3 show the locations of the ambient water temperature measurements.

Table 2.1 98^{th} percentile temperatures of the ambient water at different locations.

Location ID	98^{th}- percentile Temperature (°C)	Average depth (cm) from surface	Data frequency
BEERKNMDN	20.50	-100	<monthly
HOEKVHLD	22.00	-185	hourly
HOEKVHLD	20.90	-250	hourly
HOEKVHLRTOVR	21.90	-250	hourly
HOEKVHLRTOVR	21.60	-450	hourly
HOEKVHLRTOVR	20.7	-900	hourly
BRIENOD	23.70	-100	< monthly
BRIENOBRTOVR	24.00	-250	hourly
BRIENOBRTOVR	24.00	-650	hourly
KINDDLKOVR	24.00	-500	hourly

Figure 2.2 Locations of ambient water temperature measurements (www.waterinfo.rws.nl).

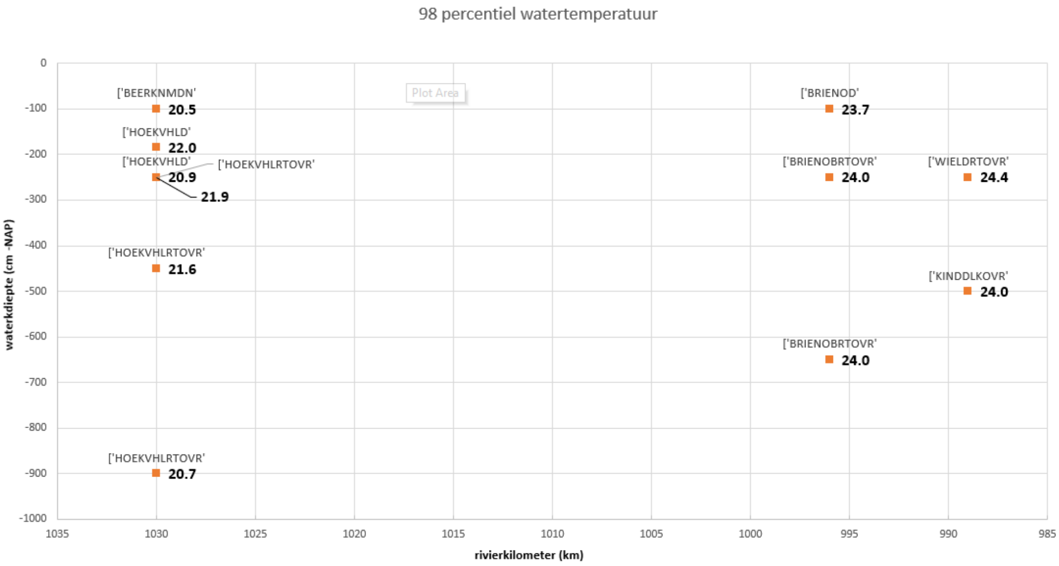

Figure 2.3 Information on vertical distribution of the available ambient water temperature measurements.

To define the background temperature at the edge of the water body, the above data was reviewed and analysed. The measurements showed that the water temperature data at BEERKNMDN and BRIENOD have low temporal resolution and were therefore omitted from the analysis. Water temperature measurements were made available at different depth levels (between 1m to 9m from the water surface). Limited measurements are available between the Kinderdijk and Hoek van Holland river stations. The 98th percentile ambient temperature at the project site was derived between 20.5°C and 22.0°C with a vertical temperature difference of 1°C (due to salt intrusion). At the river side the temperature was derived at 24°C.

The environmental criteria state that the background temperature is defined as the temperature at the edge of the waterbody. At the Maasvlakte area, the edge of the waterbody is close to the Botlek region. A representative background temperature at the edge of the water body was defined by linearly interpolating the measurement data between HOEKVHLD and BRIENOBRTOVR at the edge of the water body location. The highest values in the vertical were used (more conservative) to define the representative background temperature. This was computed as 22.96 °C.

2.4 Ambient hydrodynamic conditions

The environmental criteria require that the plume dispersion is assessed for low river discharge conditions. To assess the river flow conditions at the Maasvlakte, model conditions from the RMM model were analysed. Figure 2.4 presents the river flows of the contributories in Maasvlakte estuary for the year 2018. The green line indicates the sum of all riverine flows. Low river flows occurred around October with flows around 1000 m^3/s, while peaks flows of more than 7000 m^3/s were computed in January of the year 2018.

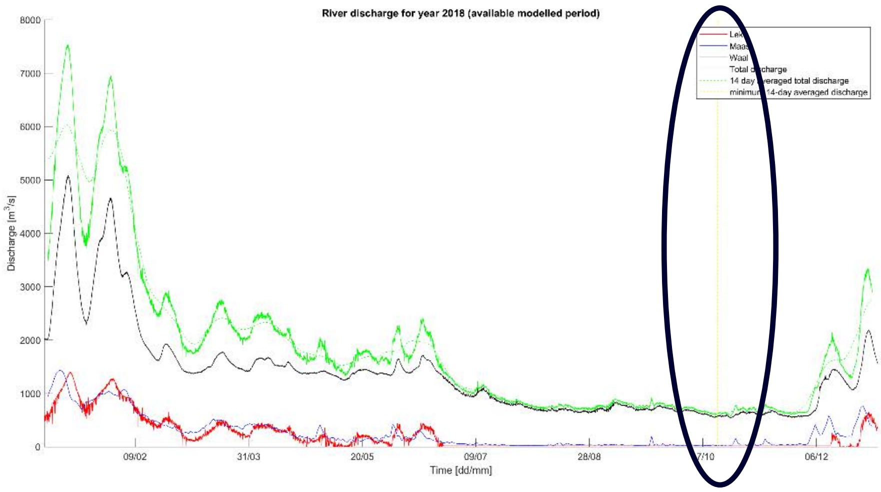

Figure 2.4 River discharge timeseries for the year 2018. The circled area indicates the low river discharge period during the year 2018.

2.5 Present outfalls in Maasvlakte area

No suitable discharge data was available for the existing plants in the Maasvlakte area and these existing operations could therefore not be included reliably in the modelling. Nevertheless, eventually these existing operations need to be included in the environmental impact assessment to assess the cumulative effects. To support this at this initial stage, sensitivity analyses were carried out to assess the influence (if any) of existing thermal discharges.

2.6 Maasvlakte cooling water discharges

The purpose of this first cooling water study for the Maasvlakte is to evaluate different intake and outfall options and discharge characteristics in relation to the applicable environmental criteria. No detailed designs or discharge characteristics were available at the start of this assessment. Therefore, together with EZK, different cooling water discharge characteristics and intake and outfall options for the Maasvlakte plant were selected to be assessed in the present study.

2.6.1 Thermal discharge capacity, flow and discharge temperature

The maximum electrical capacity of the NPP is currently estimated at 2x1600 MWe with an estimated efficiency of 35%. The proposed power plant (2x1600 MW electrical capacity) has a total thermal capacity of 4600 MW_{th}. This results in (4600-1600)*2 = 6000 MWth of heat discharge for a once-through cooling system. Since it is unknown at this point at which temperature increase the cooling water will be discharged, 3 different combinations of discharge flow and a temperature increase between the intake and the outfall are considered:

- Discharge option 1: A discharge of 205 m^3/s and a temperature increase of +7°C.
- Discharge option 2: A discharge of 159.5 m^3/s and a temperature increase of +9°C.
- Discharge option 3: A discharge of 119.5 m^3/s and a temperature increase of +12°C.

Next to the assessment of a thermal discharge of 6000 MW_{th}, also a thermal discharge of 4000 MW_{th} is assessed, which is the lower end of the expected range and is associated with a possible different type of reactor.

2.6.2 Intake and outfall options

For the NPP cooling water system, 7 intake and outfall configurations were assessed (as agreed with EZK), see Figure 2.6. Configurations differ by the locations of the intake and outfall, type of intake/outfall (submerged or open) and the use of structures (i.e., breakwaters). The 7 intake and outfall configurations are summarised below. For the purpose of this study, in order to clearly delineate the positions of intake and outfalls within the Maasvlakte area, we divided the area into three distinct regions as illustrated in Figure 2.5.

Figure 2.5 Project site regions as defined in this report.

- **Configuration 1**: Open outfall at the North side, open intake in the Harbour side.
- **Configuration 1b:** As Configuration 1, including breakwater structures of about 200 m length around the open outfall.
- **Configuration 2**: Submerged outfall at the North Side, open intake at the Harbour side.
- **Configuration 3**: Open outfall at the West side, open intake at the Harbour side.
- **Configuration 4**: Open outfall at the Harbour side, open intake at the North side.
- **Configuration 5:** Open outfall and open intake at the West side.
- **Configuration 6:** Submerged outfall and open intake at the West side.

When compiling these indicative configurations, not all factors that could influence the ultimate feasibility of these configurations were taken into account. In this first phase of the project, the obvious aspects have been considered, but the developers, in consultation with the authorities, will have to look in more detail at the feasibility of the configurations considered by the developer. This applies to the heat aspect, but also other aspects such as operational, ecological and safety aspects.

Furthermore, no detailed designs of the intake and outfall structure have been made due to the preliminary nature of this assessment. It is however noted that specific criteria exist for the intake and outfall structures. This includes, amongst others, criteria for fish entrainment and impingement of the intake structure to which the intake needs to comply.

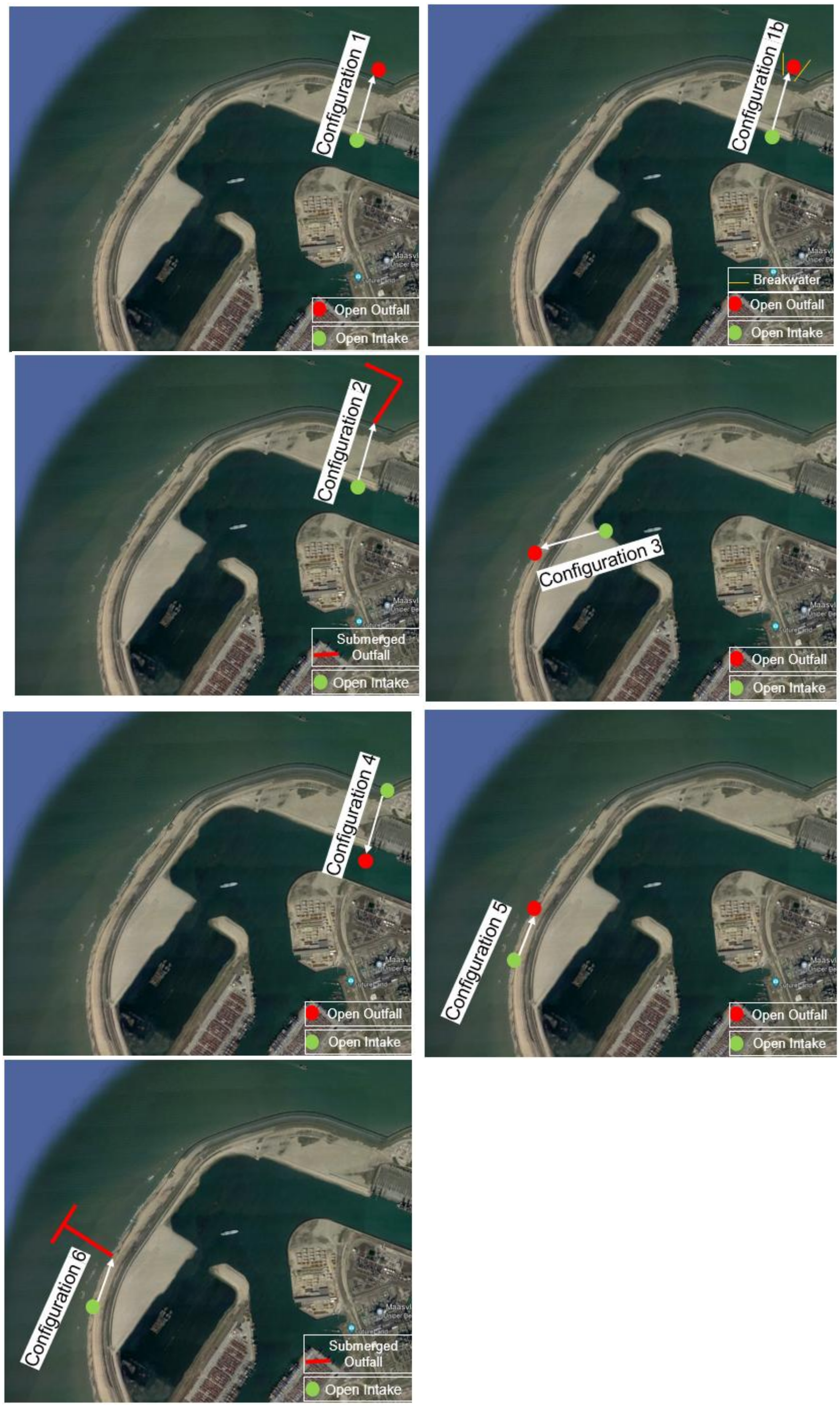

Figure 2.6 Different Maasvlakte intake and outfall configurations modelled in this assessment.

3 Setup of the detailed Delft3D model

To assess the plume dispersion and recirculation of discharged cooling water in the Maasvlakte area, a detailed far field model is needed. This far field model should be capable of simulating the important hydrodynamic processes for the plume dispersion with sufficient horizontal and vertical resolution as well as the heat exchange with the atmosphere. In the present assessment, a dedicated three-dimensional model was setup using Delft3D 4 software. Hydrodynamic boundary conditions for this detailed model were derived from available D-FLOW FM validated model RijnMaas Monding (RMM3D), see Figure 3.1. This chapter presents the model set up of the detailed model.

3.1 Overall model – RMM3D

In the past years, within the framework of the KPP programme Hydraulic Schematisations Freshwater and Salt, Rijkswaterstaat commissioned to Deltares, the development of a three-dimensional model schematisation for the Rhine-Meuse estuary (RMM) running under D-HYDRO was carried out, Deltares (2023).

The RMM3D model serves as an official schematization for salt intrusion issues in the Rhine-Meuse estuary. The model schematization has been set up for a wide range of river discharges and has been validated for situations of low discharges in the periods of 2011 and 2018, see Figure 3.2 and Figure 3.3. The RMM3D model was used as an overall model to derive the hydrodynamic boundary conditions for the detailed model. This model was run with boundary conditions of the year 2018 (which is a recent validation year), but including all recent geometrical features (i.e., bathymetry, structures etc) to derive the hydrodynamic boundary conditions for the detailed model. The boundary conditions were written to the output file with an interval of 10 minutes.

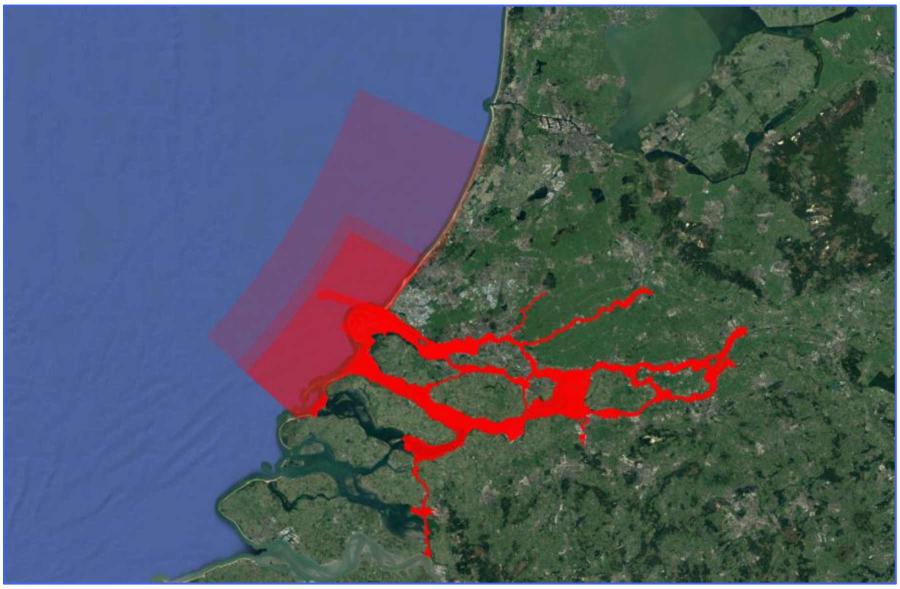

Figure 3.1 Model domain of the overall RMM3D model.

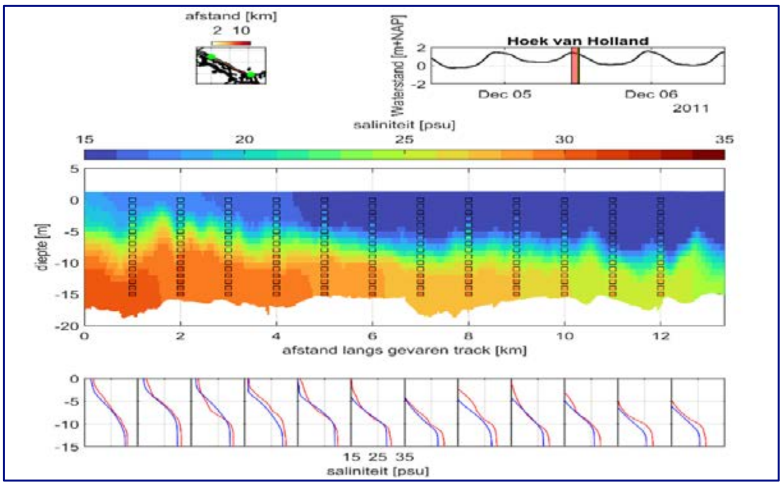

Figure 3.2 Salinity validation plot at Hoek van Holland for the Overall model.

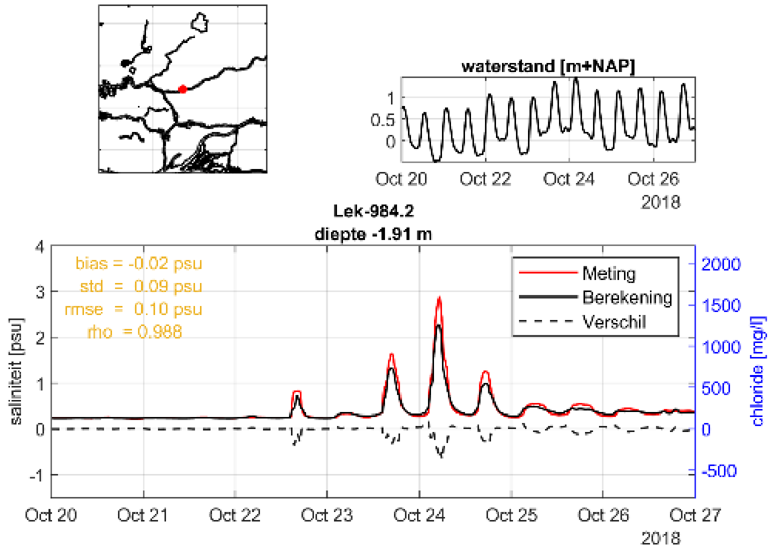

Figure 3.3 Salinity validation plot near Lek for the Overall model.

3.2 Detailed model - Maasvlakte

3.2.1 Computational grid detailed model

A new detailed computational grid was set up for the Maasvlakte area. The grid covers an area of about 30 km in alongshore and 17 km in cross-shore sea-side direction, see Figure 3.4. The estuary side of the model extent was based on the expected maximum distance the discharged cooling water could reach within a tidal cycle (i.e., to ensure that the cooling water plume remains in the model domain and to limit boundary interactions). The computational grid makes use of the curvilinear grid approach with high resolution near the project site and lower grid resolution at the model boundaries. Near the project side the model grid has a resolution of about to 40 m by 40 m, see Figure 3-5. Towards the model boundaries the grid resolution increases to more than 100 m by 100 m. In total the grid consists of 339 x 331 grid cells.

The horizontal coordinate system of the grid is Amersfoort / RD new. In the vertical, the sigma approach was used for the vertical grid layer distribution. This means that the grid layers are distributed according to a fixed percentage of the local water depth. The present model contains 20 vertical layers with uniform distribution. The layer thickness is equal to 5% of the water depth. Due to relatively shallow depths in the area this ensures sufficiently high vertical resolution for the thermal plume.

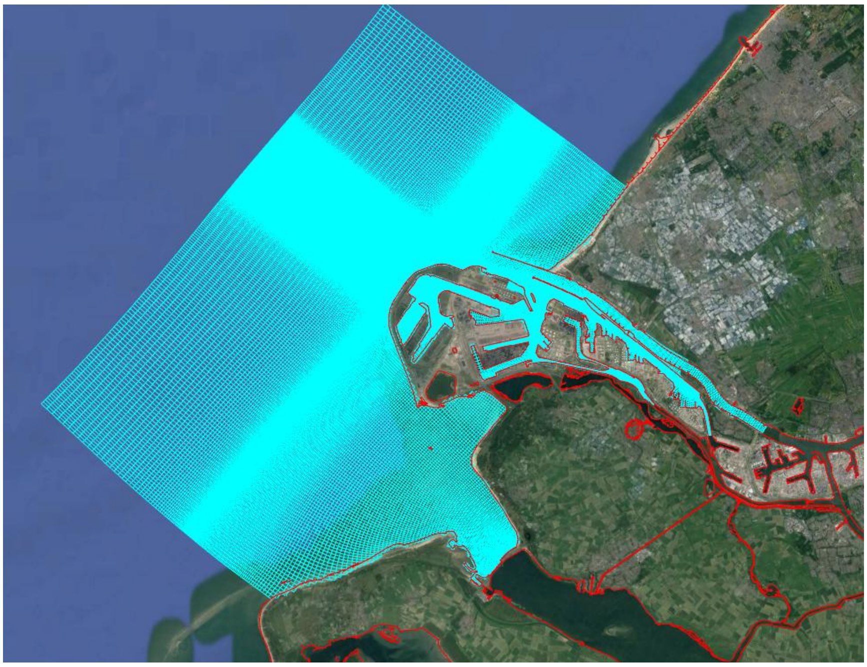

Figure 3.4 Computational grid of the detailed Delft3D-FLOW model.

Figure 3-5   Zoomed in plot of the computational grid of the detailed Delft3D-FLOW model near project site area.

3.2.2 Model bathymetry

The model bathymetry was based on the RWS Baseline data, see Section 2.1. This data was interpolated to the model grid. Since the survey data was already provided with reference to NAP, no changes needed to be made to the vertical reference of the data, except that the model depth is defined positive downward. The final model bathymetry is presented in Figure 3-6.

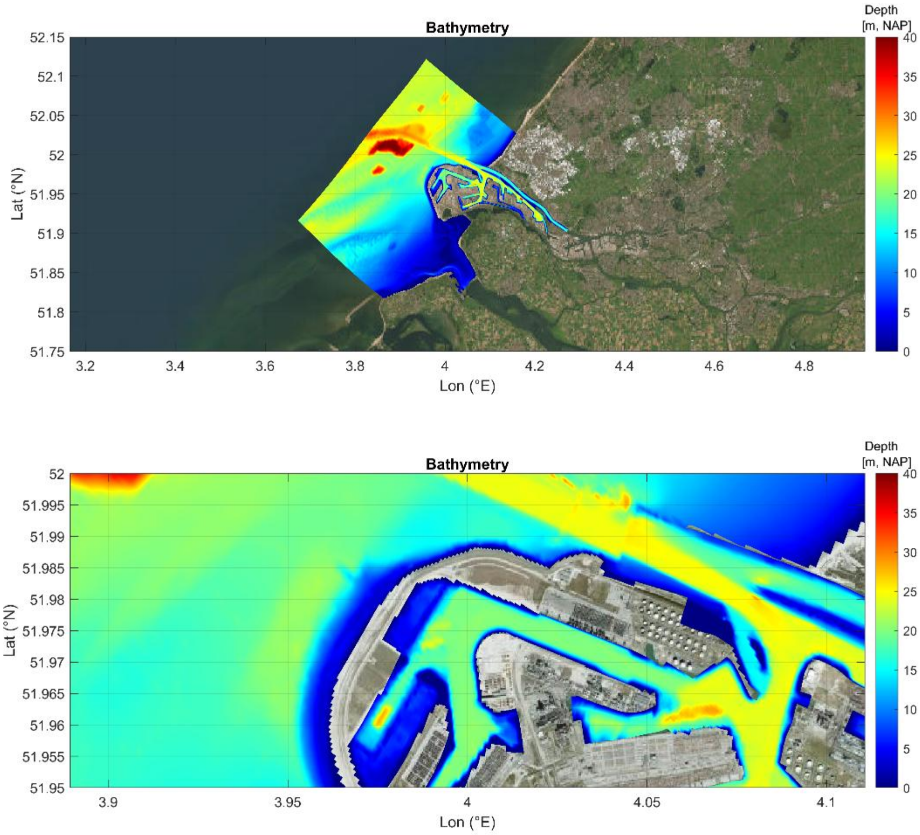

Figure 3-6   Bathymetry of the detailed Delft3D-FLOW model.

Furthermore, the latest satellite images were analysed to obtain the latest status of breakwaters, jetties and/or other geometrical features that could affect the hydrodynamics and plume dispersion in the area.

3.2.3 Boundary and forcing conditions

The detailed Delft3D model has four open boundaries of which three are at the North Sea side and one at the river side. The model consists of water level boundaries at the North Sea side, 3D discharge boundaries at the river side and 3D salinity boundaries at all boundary sections.

In Maasvlakte area, the freshwater river discharge and the salt water from the sea can lead to strongly stratified flows in the Nieuwe Waterweg. Stratification refers to the formation of a distinct horizontal layering over the water column resulting from the interaction between salt water from the sea and freshwater from the river discharge. Stratification can influence the top-layer flow velocities since the stratification interface is very smooth and allows for higher flow velocities in the upper part of the water column. In addition to that, stratification influences the vertical mixing. The denser water at the bottom prevents the lighter water at the surface from sinking or mixing. These complex processes are important to account for in the present study to accurately assess the mixing processes and plume behaviour of the envisioned intake and outfalls in the area.

The boundary conditions of the detailed model were obtained from the Overall hydrodynamic model (RMM3D) for the low river discharge period within the year 2018. The performance of the detailed model was verified against the results of the validated RMM model to ensure that the model provides accurate results. Figure 3.7 shows the water levels at a location close to the project site for the overall and the detailed models. Figure 3.8 shows depth averaged current flows at a location close to the project site for the overall and detailed models. This figure shows that the peak velocities are very similar to the overall model, but that the lower peaks are slightly underestimated by the detailed model. For the present modelling study, this slight underestimation would result in somewhat less plume dispersion and is therefore considered to be on the conservative side (although the effects are expected to be limited). The vertical salinity profile near the Maasvlakte area can be seen in Figure 3.9. These figures show that the simulated hydrodynamic conditions with the validated overall model are accurately transferred to the detailed model. The small differences obtained between the overall and detailed model with respect to salinity variations, are further assessed with sensitivity modelling scenarios to see any possible influences on the plume behaviour. The plume behaviour results show no significant differences between these runs therefore the model is considered reliable tool for the present assessment, see Section 4.4.2.

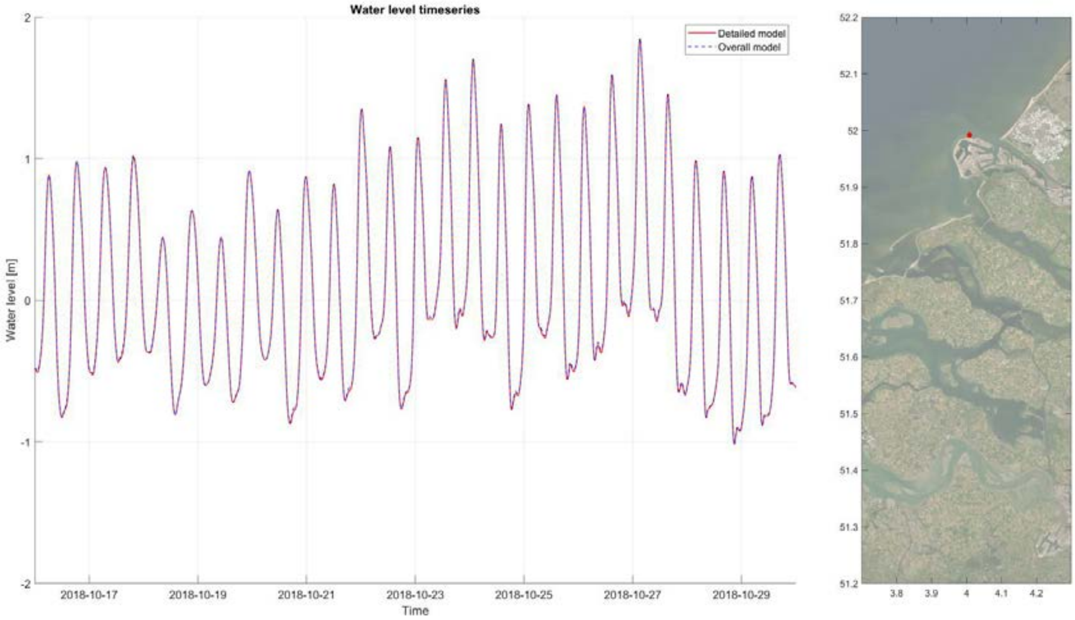

Figure 3.7 *Water level timeseries plots for verification of the Detailed model. The red line shows the computed water levels of the Detailed model and the blue dashed lines the water levels computed by the Overall model.*

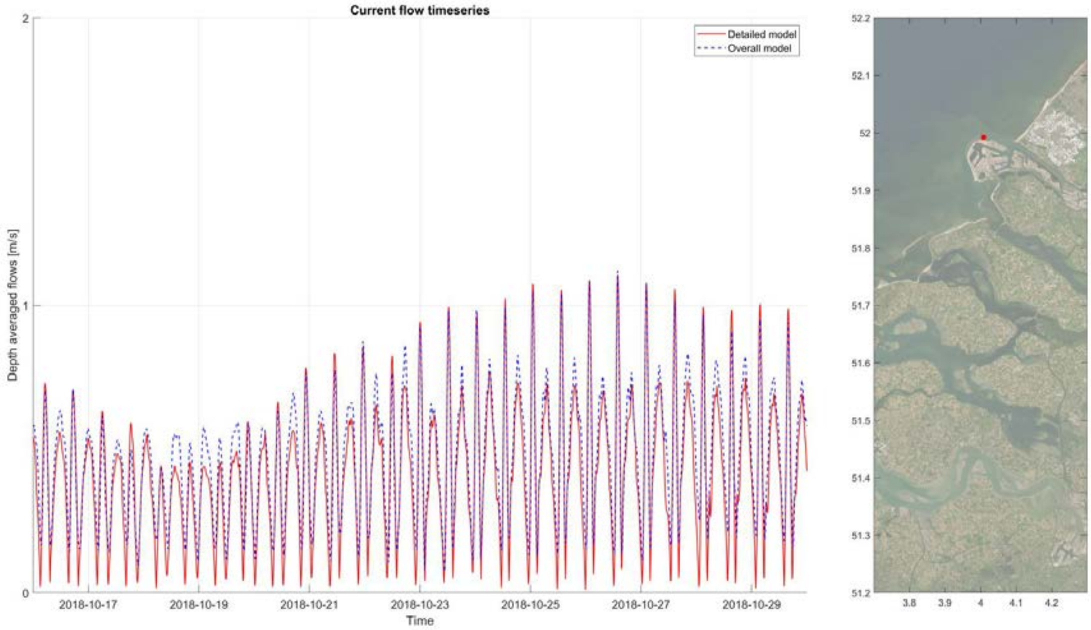

Figure 3.8 *Depth averaged current flow timeseries of the Detailed model. The red line shows the computed depth averaged currents of the Detailed model and the blue dashed lines the depth averaged currents computed by the Overall model.*

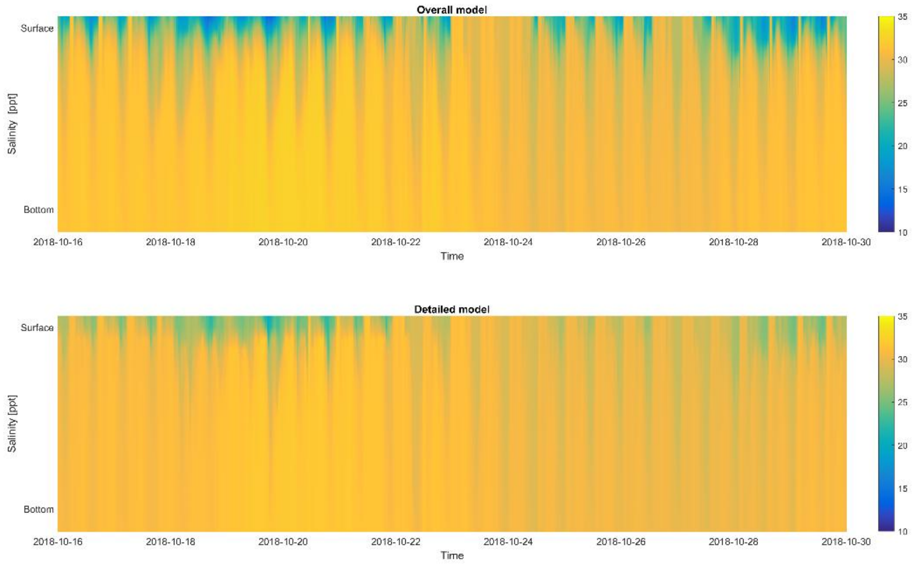

Figure 3.9 Verification of the vertical salinity profile between the overall and detailed model near the project site area.

Spatially uniform wind time series were applied based on ERA5 dataset, European Centre for Medium-Range Weather Forecasts' (ECMWF) (see https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5).

To limit any boundary interaction of the cooling water plume, a Thatcher-Harleman time lag was applied at the boundary with a value of 720 minutes.

For the temperature modelling, the excess temperature heat flux model of Delft3D was used (Sweers, 1976). This heat flux model calculates the net heat flux based on the temperature difference between the air and the water surface and the wind conditions. By setting the background temperature equal to the air temperature and both constant in time, the impact of the outfall could be derived directly from the modelling. Since part of the CIW criteria is based on maximum temperatures above background conditions, this approach is considered the most suitable for the present assessment. In all simulations a uniform background water and air temperature of 22°C was used. The background temperatures are however not important for the plume dispersion results since in the analysis of the simulations the background temperature was subsequently subtracted from the modelling to obtain the excess temperature due to operation of the outfall only. For interpretation of results and to assess the compliance with environmental criteria, the ambient temperatures were used as derived in Section 2.2. In relation to the maximum 25°C criterion, the computed temperature increase is used in combination with the derived background temperature.

3.2.4 Other model parameter settings

Various other Delft3D model parameters were set based on experience and/or validation of the plume dispersion in other projects:

- The bottom roughness was used with Manning coefficient value of 0.023, consistent with the validated overall model.
- The background horizontal eddy viscosity and diffusivity were set to 1 m^2/s.
- The 3D turbulence was computed by the k-Epsilon model.
- A uniform background vertical viscosity of $1*10^{-5}$ m^2/s was used.

- The simulation period was set from 09 October 2018 to 30 October 2018, i.e., the period with the lowest river flow in 2018. Note that only the period of the last 14 days (i.e., a spring-neap tidal cycle) was used for the postprocessing.
- The model time step was set to 0.2 min.
- Model output was generated at a 10-minute interval for point locations and 30-minute interval for map output.
- Gravity was set to 9.81 m/s^2.
- The air density was set to 1.205 kg/m^3.

3.3 Near-field schematisation of submerged outfalls

Different types of outfalls were considered in the present assessment. Open outfalls are typically shore-based structures with limited initial mixing and are simulated directly in the Delft3D far field model. Submerged outfalls aim to rapidly mix the cooling water with ambient water in the first tens of meters. The mixing close to the submerged outfall depends on the discharge momentum, small-scale turbulence and other non-hydrostatic processes. Further away from the outfall the spreading and mixing of discharged cooling water depends on ambient (hydrodynamic) conditions like the bathymetry, currents, meteorological conditions etc. These different stages of the outfall plume are typically classified as the near field and far field domain. Since a single model cannot assess these two stages simultaneously, both near and far field assessments need to be performed to accurately assess the spreading and mixing of an outfall plume.

In the present assessment the near-field behaviour of the submerged outfall thermal plume was assessed by means of the CORMIX expert system (www.mixzon.com). CORMIX computes the hydrodynamic behaviour of the outfall plume close the outfall including the plume trajectory and dilution. The results of the near field assessment are subsequently coupled to the far field model with use of Deltares' C-SUMO (Coupled Subgrid Model) system. This ensures that the near-field characteristics of the plume behaviour are included in the overall modelling assessment in a physically correct way.

Since no detailed outfall design was specified in this first assessment, a number of sensitivity tests with different submerged outfall configurations (e.g., outfall diffuser configurations) were performed with CORMIX to obtain a typical and realistic near-field behaviour and near-field dilution. For reference, the schematic design eventually considered in this assessment consists of a diffuser layout with a total length about 300 m, 8 discharge ports all pointing in offshore direction at an average local depth of 15 m, see Figure 3.10. Port diameters varied between approximately 2.5 m and 3 m depending on the discharge flowrate. The diffuser layout is similar to the layout used in the Borssele study (Deltares, 2023) and has not been optimised for hydraulic performance in this initial assessment.

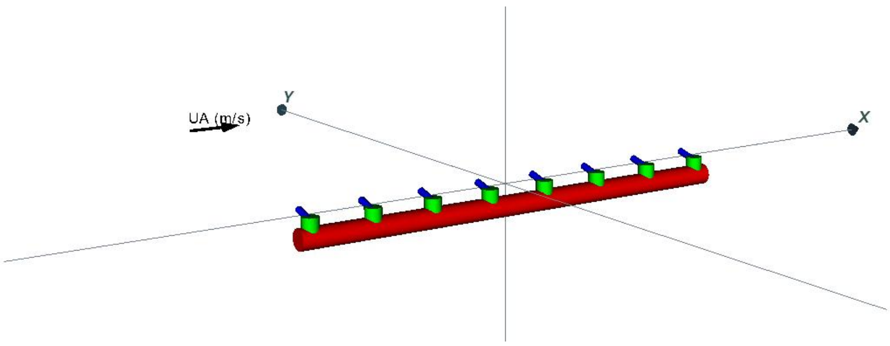

Figure 3.10 Schematic representation of the submerged outfall diffuser.

The expected plume behaviour of this schematic submerged outfall design was assessed for various ambient conditions and CORMIX schematisations. CORMIX simulations were performed with water levels varying from -1 m to 2 m NAP with increments of 1 m and ambient current velocities from 0.25 to 1.75 m/s with increments of 0.25 m/s. For this outfall design and considered ambient conditions, the dilution varies between approximately a factor of 3 for low water levels and low current conditions, and a factor of 39 with high water levels and currents at the end of the near field. The coupling location to the far field model was defined as the location where the width of an individual plume (i.e., from 1 port) exceeds the model grid resolution (~40m) and where most of the non-hydrostatic effects of the plume have diminished. It is noted that CORMIX does not consider large-scale re-entrainment, i.e., build-up of effluent near the outfall during low ambient flow conditions, and the effective dilutions may in practice be lower and thus excess temperatures higher compared to what is computed in the near field simulations alone. The build-up of effluent is however properly simulated in the Delft3D far field model by means of the C-SUMO coupling method.

The near field results are stored in a look-up table database which is coupled to Delft3D using Deltares C-SUMO software. C-SUMO facilitates the coupling of different near-field and far field models, as well as databases with results from dedicated near field assessments. During a far field simulation, C-SUMO selects the best representative case from the set of near-field results based on the ambient conditions at that moment. For this assessment, the plume dimensions and dilution that best fit the water level and current conditions are selected and mapped on the far field grid. The interval for which the near-field results are updated in the far-field model is 60 minutes. The information stored in the database includes information on the x-y-z coordinates of the plume centreline, the plume width, the plume thickness and the dilution along its trajectory. The location where the plume width exceeds the Delft3D grid resolution and will spread under the influence of ambient (current) conditions, was considered as the coupling location to the far field model.

For accurate representation of the plume trajectory and near field mixing in Delft3D the Distributed Entrainment Sinks Approach (DESA) of Choi and Lee (2007) was used. The DESA-method uses series of sources and sinks in the Delft3D model to represent the initial mixing of the plume in the near field with ambient water, this is illustrated in Figure 3-11 This dynamic coupling with the DESA-method ensures that the plume characteristics are well represented in the far field model domain which allows for a more accurate assessment of the outfall plume dispersion compared to traditional modelling methods.

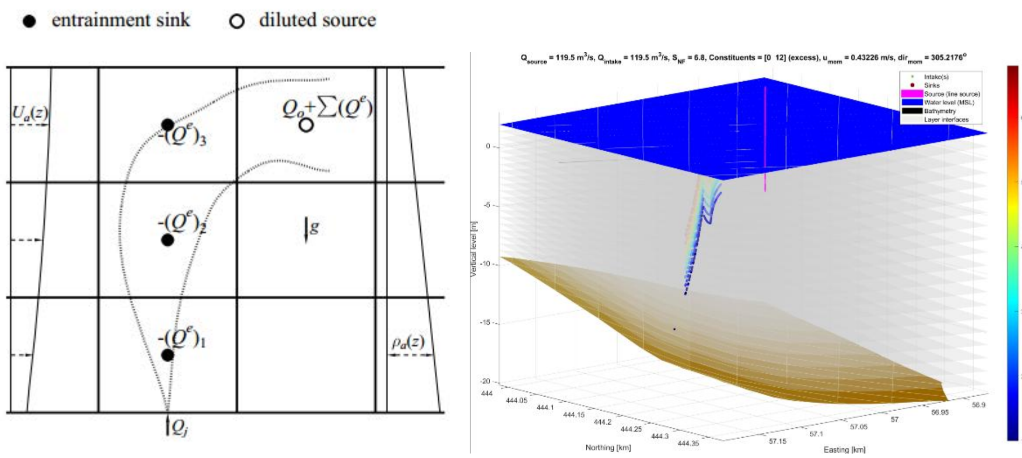

Figure 3.11 Schematics of the DESA-method (left) to represent the near-field plume mixing in the far field model by series of sources and sinks (from: Choi and Lee, 2007) and the DESA-method approach for a 8 port diffuser in the present assessment.

4 Modelling results of the plume dispersion

With the coupled Delft3D-FLOW model and near-field database, several outfall plume simulations were carried out for the different scenarios (i.e., different intake and outfall configurations, different thermal discharge capacities, discharge characteristics, structures etc.). The objective of the present assessment is to assess the expected plume dispersion in relation to the environmental temperature criteria and the recirculation towards the intake. This chapter presents an overview of the simulated scenarios and their results in relation to these operational and environmental criteria.

4.1 Overview of the simulations

Based on the different intake and outfall configurations, discharge characteristics, thermal discharge capacities and optional structures, 17 simulations were carried out to assess the cooling water plume dispersion of the new nuclear power plant at the Maasvlakte site. These simulations include sensitivity analyses on the salinity boundary conditions to validate the modelling performance and effluent heat temperature to assess the possible influence of existing outfalls in the area (that are not explicitly included in the present modelling due to the absence of information about the existing outfall operations at the time of this study). All simulations were performed for the period of from 09 October 2018 to 30 October 2018. An overview of the performed simulations is presented in Table 4.1.

Table 4.1 Overview of the simulated modelling scenarios.

Case	Thermal Capacity	Discharge option/Cooling water temperature increase	Background temperature	River discharge	Configuration	Run code	Modified parameters
0	-	-	98th- percentile	Low	-	Case 0	-
1	6000	2/+9°C	98th- percentile	Low	1	Case A-1_2	-
2	4000	2/+9°C	98th- percentile	Low	1	Case B-1_2	-
3	6000	1/+7°C	98th- percentile	Low	1	Case A-1_1	-
4	6000	3/+12°C	98th- percentile	Low	1	Case A-1_3	-
5	6000	2/+9°C	98th- percentile	Low	2	Case A-1_2	-
5b	6000	3/+12°C	98th- percentile	Low	2	Case A-1_2	-
6	6000	2/+9°C	98th- percentile	Low	3	Case A-3_2	-
7	6000	2/+9°C	98th- percentile	Low	4	Case A-4_2	-
8	6000	2/+9°C	98th- percentile	Low	5	Case A-5_2	-
9	6000	2/+9°C	98th- percentile	Low	6	Case A-6_2	-
9b	6000	3/+12°C	98th- percentile	Low	6	Case A-6_2	-
10	6000	2/+9°C	98th- percentile	Low	1	Case A-1_2	Modified salinity at the riverine boundary
11	6000	2/+9°C	98th- percentile	Low	1	Case A-1_2	Uniform salinity at the riverine boundary
12	6000	2/+10°C	98th- percentile	Low	1	Case A-1_2	Additional excess heat

Case	Thermal Capacity	Discharge option/Cooling water temperature increase	Background temperature	River discharge	Configuration	Run code	Modified parameters
13	6000	2/+11°C	98th- percentile	Low	1	Case A-1_2	Additional excess heat
14	6000	3/+12°C	98th- percentile	Low	1	Case A-1_3	Including breakwater structures

4.2 General flow and outfall plume behaviour

Maasvlakte is a part of the Port of Rotterdam which is connected to the North Sea and Nieuwe Waterweg. The vertical tide at the North Sea and the river flows from the Nieuwe Waterweg result in mean depth averaged current flows ranging from 0.6 to 1 m/s close to the project site area, see Figure 4.1 and Figure 4.2. Figure 4.3 shows the maximum computed flows near the surface and near the bed at near the project site area.

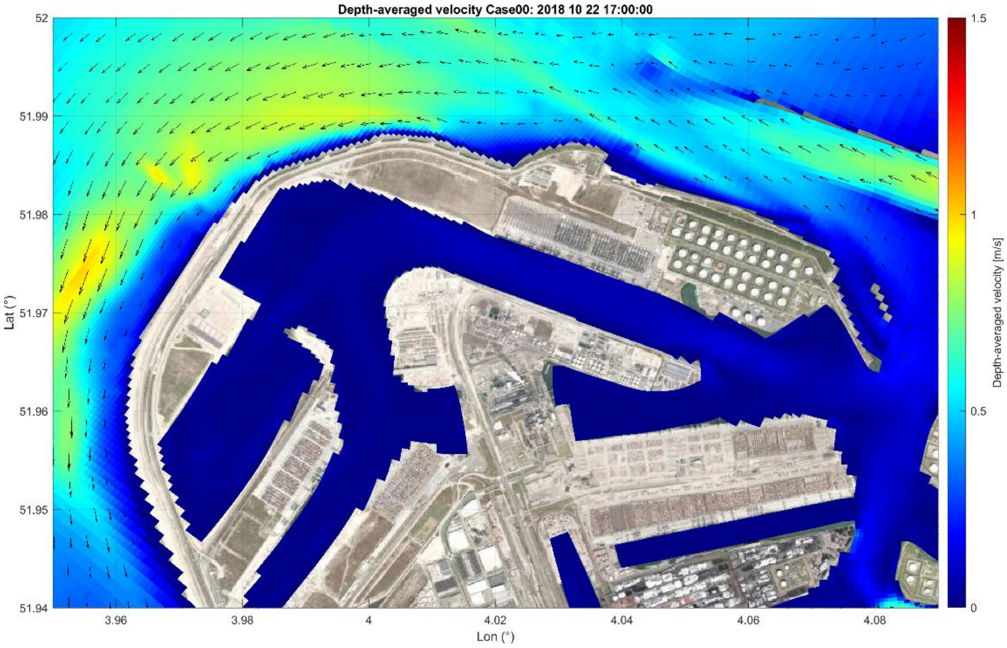

Figure 4.1 Typical depth-averaged flow velocities during ebb in Maasvlakte area.

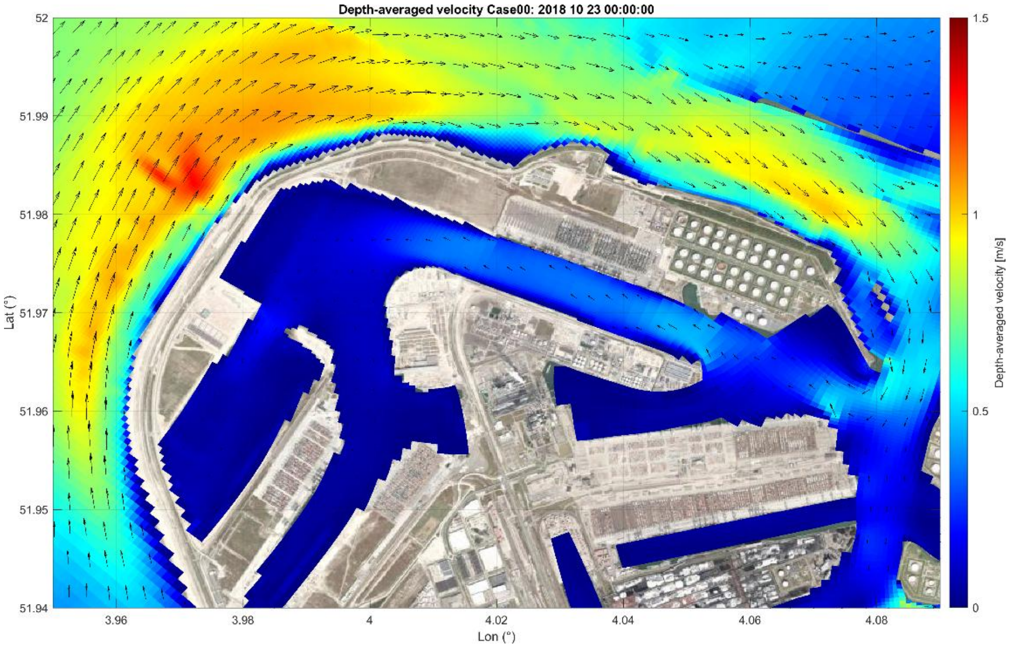

Figure 4.2 Typical depth-averaged flow velocities during flood in Maasvlakte area.

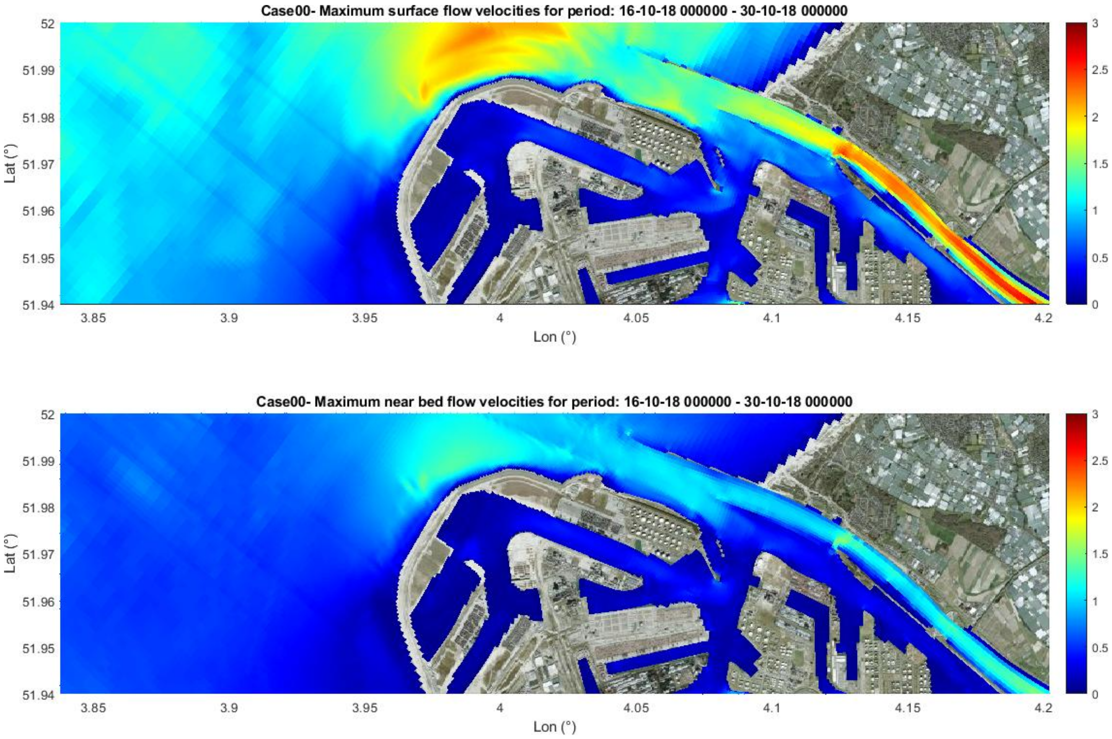

Figure 4.3 Maximum near surface (upper subplot) and near bed (bottom subplot) flow velocities computed over the full simulation period.

The spreading and mixing of the thermal cooling water discharge depend on, amongst others, these local hydrodynamic conditions around the outfall and the density difference of the outfall plume with ambient water. The thermal outfall plume is expected to spread near the water surface (due to its buoyancy) before hydrodynamic conditions cause the plume to mix or heat exchange with the atmosphere causes the outfall plume to cool down.

4.3 Presentation of modelling results

Model results are summarized and presented in relation to the environmental thermal criteria. Mean and maximum excess temperature footprints of each simulation were generated to visualise the plume dispersion for the new Maasvlakte cooling water discharge. These footprints present the increase in temperature above the background temperature due to operation of the outfall in the project area. These footprints are not instantaneous model results of the plume dispersion but combined from 672 (half-hourly interval for 14 days) individual map plots, see Figure 4.4. Figure 4.5 illustrates the difference between a mean and maximum temperature footprint.

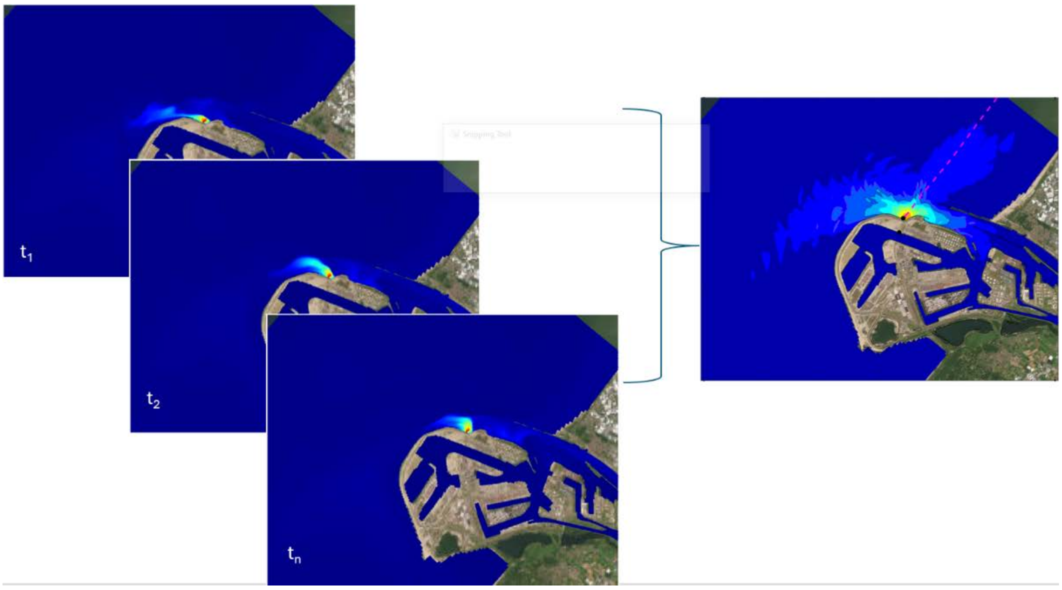

Figure 4.4 Visualisation of the maximum footprint generated from instantaneous model results.

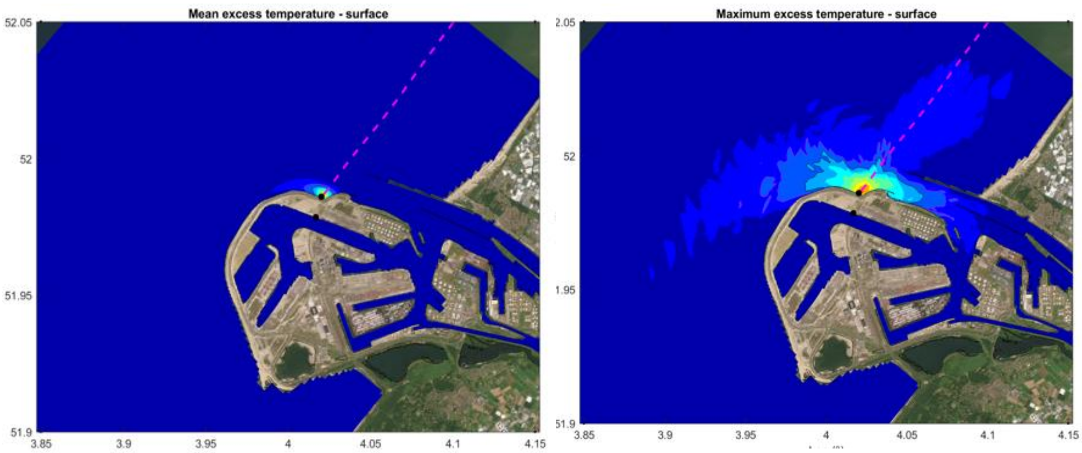

Figure 4.5 Mean (left) and maximum (right) surface temperature increase footprints derived from the simulation.

The footprints are generated for near the water surface and near the bottom for a clear understanding of the three-dimensional plume dispersion and assessment in relation to the environmental temperature criteria, see Section 2.2. Additionally, the mean and maximum temperature increase were derived from the model results at the cross-section at the outfall discharge location was drawn (magenta dashed line) for which to further illustrate the three-dimensional spreading of the plume, see Figure 4.6. The black dots illustrate intake and outfall locations. For illustration purposes the cross-sectional distance from the discharge point is limited to a distance between 500 m – 1500 m depending on the case presented.

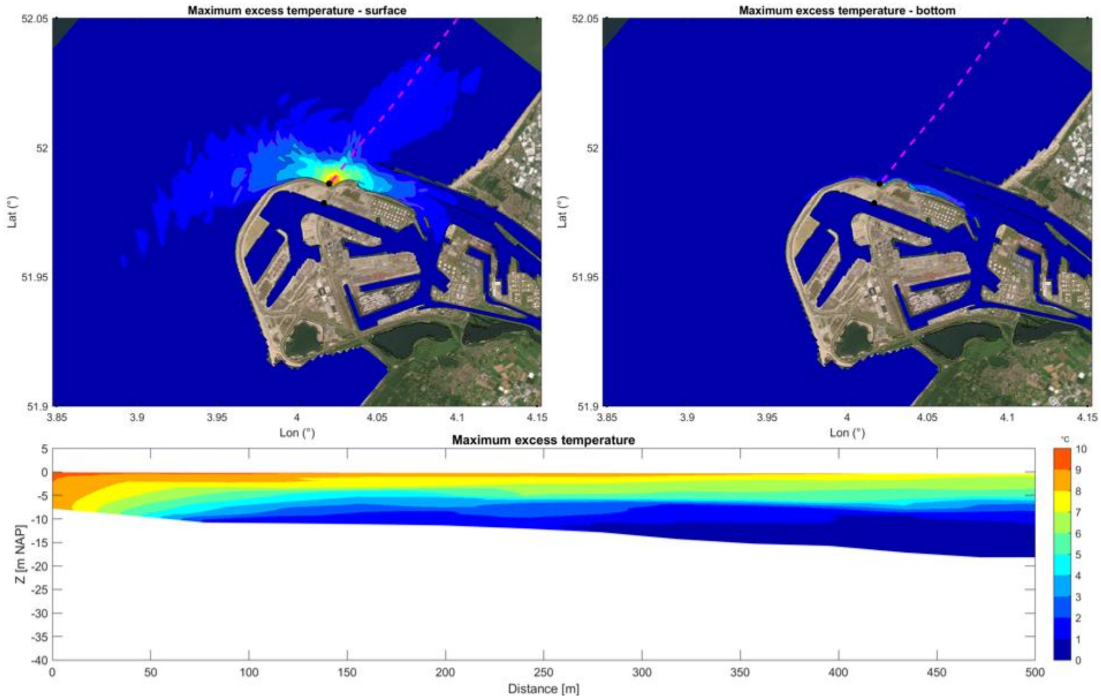

Figure 4.6 Simulated maximum temperature increase due to the thermal discharge of Configuration 1 (Case 1)

CIW mixing zone criterion in estuaries and tidal harbour areas.
The CIW environmental temperature criteria define a mixing zone as the 25°C temperature contour. For the North Sea, the CIW criteria state that the mixing zone should not touch the seabed. However, for estuaries, e.g., Nieuwe Waterweg, the CIW criterion states that the percentage of the cross-sectional area covered by the mixing zone (T>25°C) needs to be below 25%, similar to the Borssele II site evaluation (Deltares 2024). For illustration purposes in the present assessment, this criterion is also described for the estuary area affected by the presence of outfalls in Maasvlakte region. Therefore, for the present analysis the grid lines at the estuary entrance (referred to as the Maasmond) of the Delft3D model are used as cross-sections. This is roughly perpendicular to the thalweg axis. These cross-sections are visualised in the figures below. Three different parts of the model grid are used: 1) Cross-section 1 (Figure 4.7) which are cross-sections mainly in Maasmond area , 2) Cross-sections 2 (Figure 4.8) at the east side of the Maasmond area and northwest from the Nieuwe Waterweg and 3) Cross-sections 3 (Figure 4.9) at the east side of the Maasmond area and southwest from the Calandkaanal . Each figure shows the 10th gridline of the model grid, but in the analysis, all model gridlines are used. Cross-sectional areas separated by islands or dry areas are omitted from the total cross-section – only the part closest to the discharge is used as a conservative approach.

For each simulation, each output time step and each cross-section the percentage of the cross-sectional area covered by the mixing zone was calculated. These results are presented as lines in Figure 4.10(top). To derive the mixing zone from the modelling results, the background temperature derived in Section 2.3 (22.96°C) was subtracted from the critical threshold value for the mixing zone (25 °C – 22.96 °C = 2.04 °C). The computed temperature increase was subsequently compared to these excess temperature values to assess the percentages of the cross section that exceed this value.

CIW average temperature increase criterion
CIW 2004 criteria also states that the average temperature of the water body may not increase by more than 2°C and/or increase above 25 °C. The cross-sectional average temperature increase was here considered representative for the average temperature increase. The results are presented like the mixing zone criteria with the average temperature per cross-section, see Figure 4.10(bottom).

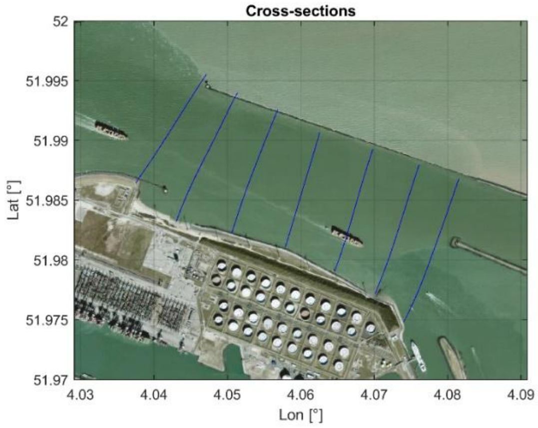

Figure 4.7 Cross section 1 covers the Maasmond area.

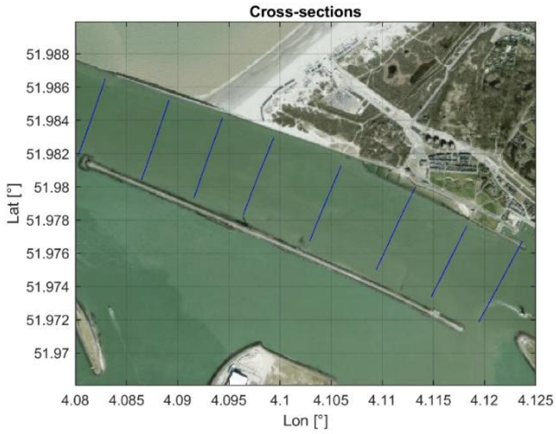

Figure 4.8 Cross section 2 covers the north-east side from the Maasmond area towards the Nieuwe Waterweg.

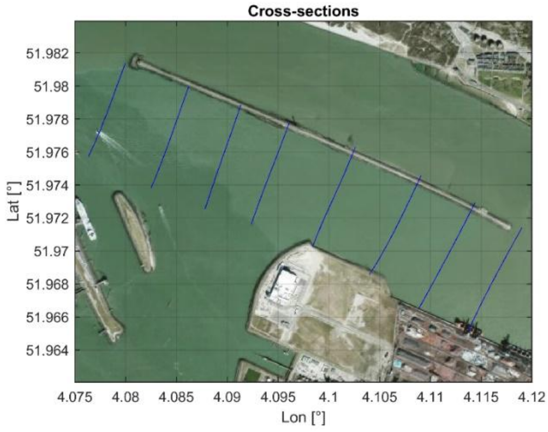

Figure 4.9 Cross section 3 covers the south-east side from the Maasmond area towards the Calandkanaal.

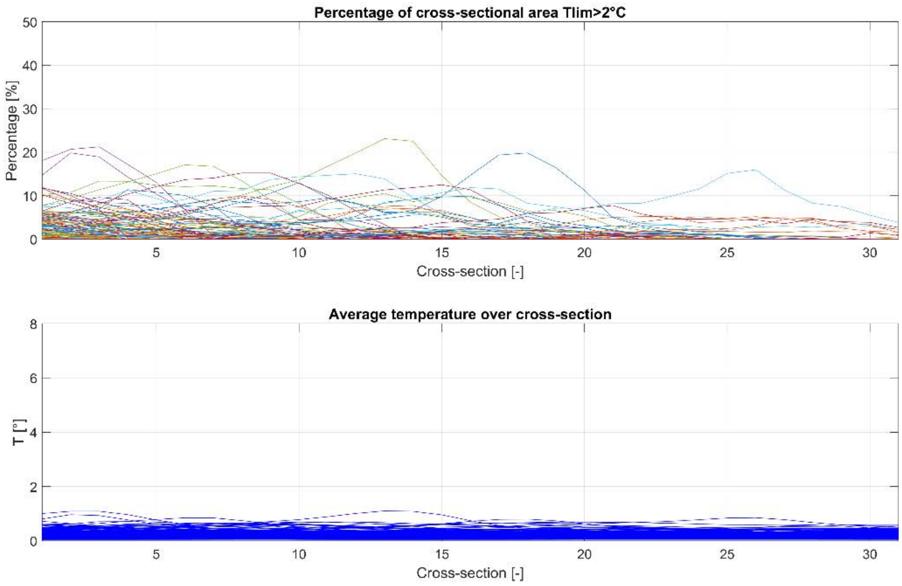

Figure 4.10 Example of the presentation of model results in relation to the environmental criteria in estuary.

4.4 Model results

Model results are presented for different intake and outfall configurations, thermal discharge capacities, discharge characteristics and the use of additional structures. A complete overview of the recirculation potential for all simulations and intakes is presented in Appendix A. In Appendix B and C, the mean and maximum temperature footprints of each simulation are presented. In Appendix D figures show the model results in relation to the CIW mixing zone and average temperature increase criterion.

4.4.1 Intake and outfall configuration Maasvlakte

In this paragraph the model results for the different intake and outfall configurations are compared. For equal comparison all configurations in this paragraph had a total thermal discharge capacity of 6000 MW, a discharge flowrate of 159.5 m^3/s and a temperature increase of +9°C between the intake and the outfall. To minimise the number of figures in the report, the most relevant figures are presented, i.e. the maximum temperature increase footprints, the percentage of the cross-sectional area covered by the mixing zone and the average temperature increase for the relevant cross-sections. A full overview of the model results can be found in the appendix as mentioned above.

4.4.1.1 Configuration 0 (Case 0)

Configuration 0 is the existing situation in the Maasvlakte area. As mentioned in Section 2.5, existing intake and outfall discharge data was not available therefore this configuration assumes zero discharges in the model. Therefore, the maximum temperature footprints have zero (constant) excess temperature.

4.4.1.2 Configuration 1 (Case1)

Configuration 1 associated with an open outfall which is located at the North Side of the Maasvlakte area and an open intake which is located at the harbour area, see Section 2.6.2. The open outfall is located at the west side of the Maasmond area towards the North Sea. Figure 4.11, shows the simulated maximum temperature increase footprint due to intake and outfall of Configuration 1, Case 1.

Due to the strong hydrodynamic flow conditions in the area, the surface plume extends about 16km alongshore the discharge location and to more than 7 km towards the cross-shore direction. Due to the high discharge flow rates in combination to the local depths, the results show that there is limited initial mixing on the first tens of meters and a high temperature increase of up to 10 °C from background conditions. Further away, at about 85m from the discharge location, the outfall plume stratifies and mixes over vertically. A maximum (surface) temperature increase of more than 2 °C is computed at distances up to 6 km along the shore. Near the bed, in the shallow areas along the coast and around the open outfall, a temperature increase over 2 °C is computed for the Maasvlakte outfall. This temperature increase is reduced at a distance of about 350 m from the coast (farther point along the coast). The mean temperature increase around the outfall for Configuration 1 is typically lower due to the dynamic behaviour of the plume, see Appendix A.

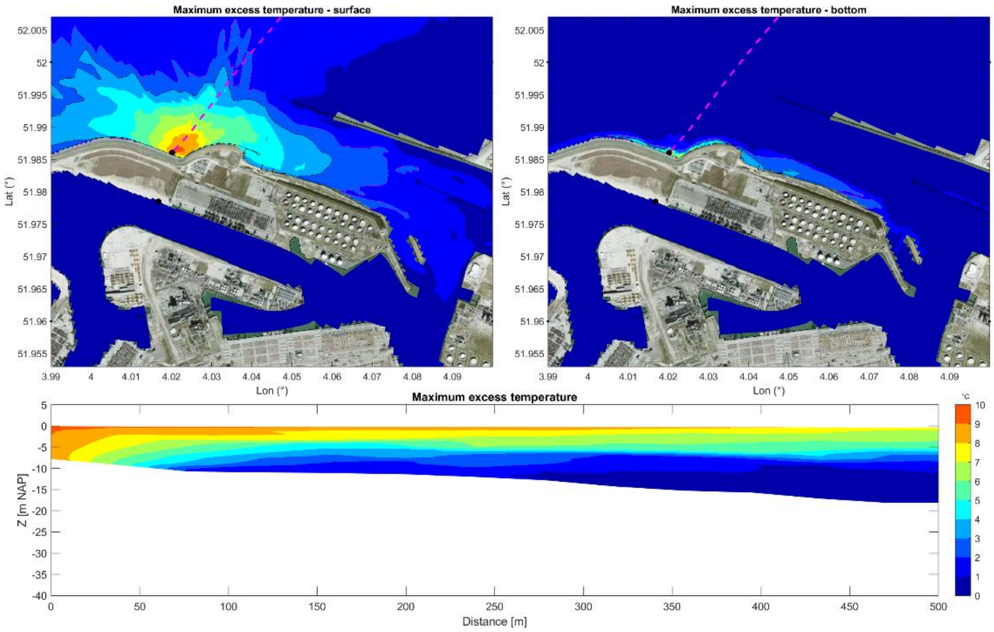

Figure 4.11 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge (Configuration 1).

Figure 4.12 shows the percentage of the cross-sectional area covered by the mixing zone and the average temperature over the cross-sections in the Maasmond area (estuary entrance). Cross section 1 which covers the Maasmond area, see Section 4.3, shows a maximum percentage covered by the mixing zone about 21% - 23% (T>2°C). It is noted that these percentages are close to the environmental temperature criterion of maximum 25% of the cross section covered by the mixing zone. Furthermore, aside from the simulated (ambient) conditions, other conditions may (temporarily) occur that could increase this percentage somewhat further. It is therefore advised to carefully consider this intake and outfall configuration in more detail, since the feasibility from an environmental temperature point of view is not obvious. The average temperature increase over the cross-sections in the Maasmond area is at maximum around 1 °C.

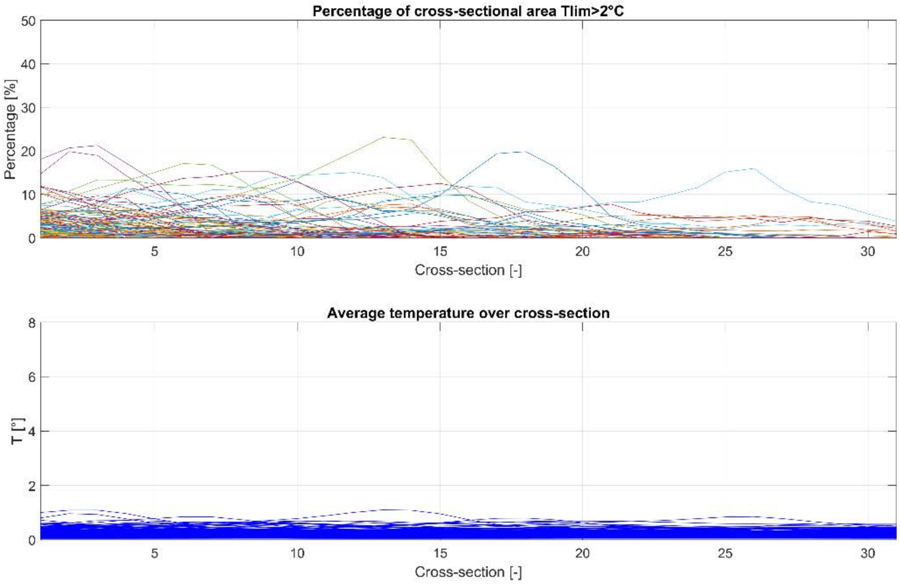

Figure 4.12 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area). Configuration 1.

The recirculation potential of the Maasvlakte open outfall towards the open intake at the harbour side, is computed to be around 0.1 °C (mean) and 0.2 °C (maximum). It is noted that these values associated with the recirculation of the new plant only and not a combined recirculation due to other existing intake and outfalls in the area, see Section 2.5.

4.4.1.3 Configuration 2 (Case 5)

In Configuration 2, the open intake remained the same as in Configuration 1, but is combined with a submerged diffuser outfall option that transfers the cooling water to about 500m offshore with the use of submerged pipe. The aim of a submerged outfall is to rapidly mix the discharged cooling water with ambient water to efficiently reduce the temperature in the direct vicinity of the outfall. The design of a submerged outfall includes several parameters that affect the near-field mixing. These parameters include the depth of the outfall, the port diameter, exit velocity, number of ports, port direction etc. Configuration 2 considers only one conceptual layout option for a submerged outfall (i.e., not further optimised). The results presented in this section should therefore serve as a first indication of the plume dispersion and recirculation of a submerged outfall diffuser.

The submerged outfall is located at a depth of about 15 m NAP at a location outside of the navigation channel (~24.20 m NAP), see Figure 4.13. Figure 4.14 presents the simulated maximum temperature footprint for Configuration 2 (Case 5). The maximum temperature footprint shows that the submerged outfall rapidly mixes the discharged heated cooling water with ambient water. Near-field simulations with CORMIX identified that with the hydrodynamic conditions in the Maasvlakte area, the considered outfall diffuser will dilute the outfall plume by a factor of 3 to 39 at the end of near-field (within several tens of meters from the outfall). The computed maximum footprint therefore shows an increase in temperature of about 2 °C to 3 °C around the outfall over the water column. The maximum computed temperature increase near the bed close to the outfall is more than 2 °C. At distances of more than 500 m away from the outfall, the outfall plume is computed to be less than a 2 °C temperature increase (also near the bed). Compared to the configurations with an open outfall in the Maasvlakte area, the submerged diffuser outfall has a smaller temperature increase near the bottom in shallow areas. For open outfall the temperature increase near the bed was typically over 3 °C at some distance from the outfall. This decreases substantially with a submerged outfall to a temperature increase below 1 °C.

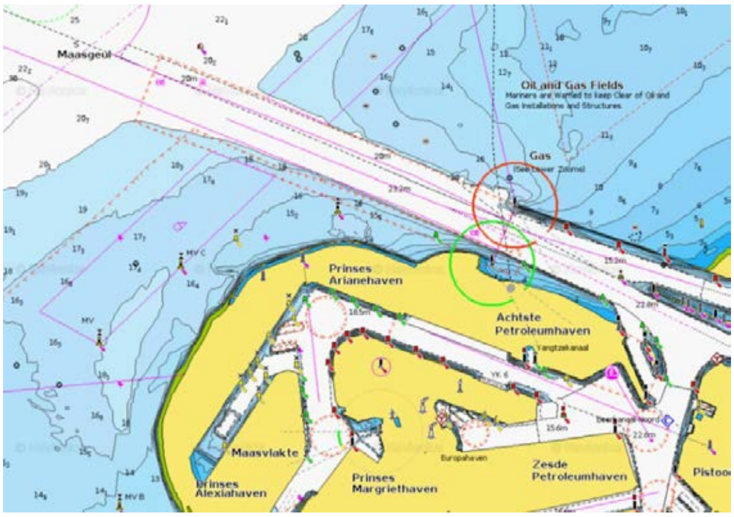

Figure 4.13 Navigational chart near the Maasvlakte area.

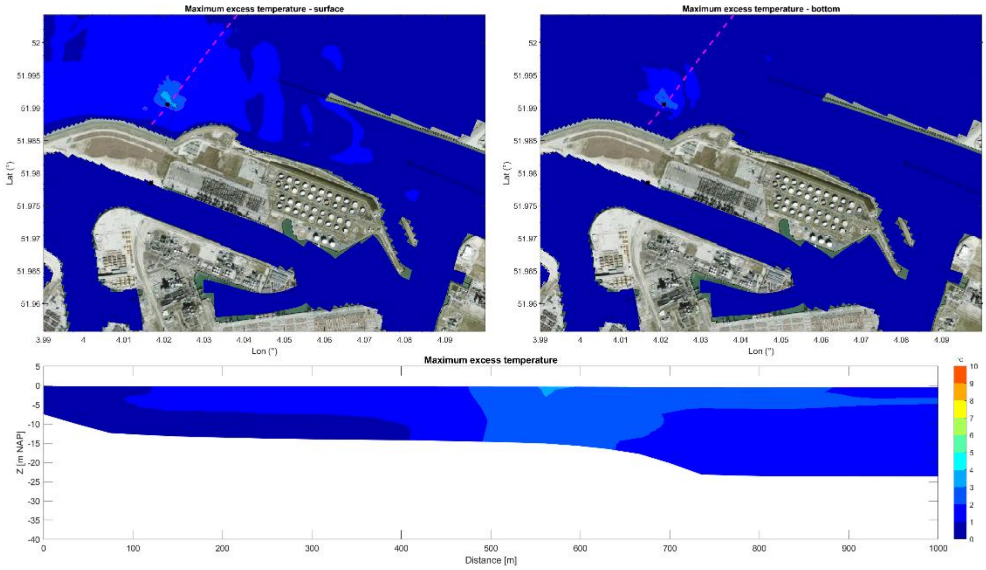

Figure 4.14 Simulated maximum temperature increase footprint by the new cooling water discharge (Configuration 2).

Similar to Configuration 1, the recirculation potential of the intake located in the harbour area is limited to less than 0.1 °C (mean) and 0.2 °C (maximum). Figure 4.15 shows the percentage of the total cross-sectional area covered by the mixing zone in the Maasmond area. This figure shows that the submerged outfall option would result in a very small mixing zone extent (<0%). The cross-sectional average temperature increase is below 1 °C.

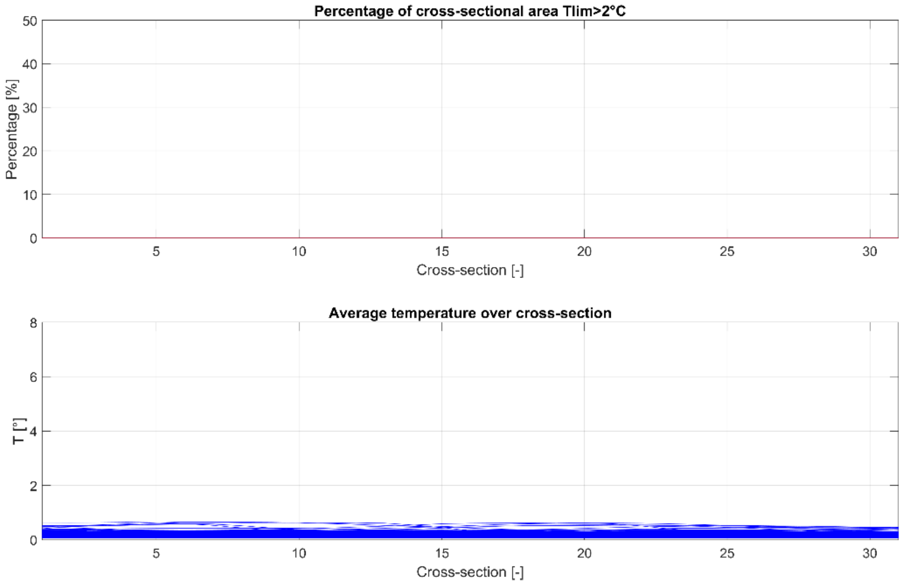

Figure 4.15 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area). Configuration 2.

4.4.1.4 Configuration 3 (Case 5)

In Configuration 3, the open intake is placed at the west of the harbour side area (inside the harbour) and the open outfall is placed at the west side of the Maasvlakte area (at the coast). The open outfall is at the North Sea coast, away from the Maasmond area. The flow dynamics of the North Sea can positively influence the mixing behaviour of the plume, however, the shallow depths along the coastline could limit the mixing. The development of an open outfall at the west side of the Maasvlakte area requires dredging operations. For Configuration 3, a dredged channel with a depth approximately 4 m (assumption, to be verified and optimised) is included in the modelling following the depth contours in the area. Figure 4.16 shows the resulted maximum excess temperature footprints.

The results show a large plume extent along the western coast with a temperature increase of more than 9°C at the discharge location and over the full water column. The shallow depths in combination with the plume thickness result in a high temperature increase at the outfall location and along the coastline. In comparison with Configuration 1, the increase in near-bed temperature of more than 2°C, is computed further offshore to a distance more than 350 m.

The location of the outfall at the west side of the Maasvlakte coast, results in a limited cross-sectional coverage in the estuary entrance. To limit the amount of figures in the main report, the cross sectional coverage percentage plot is not presented for this case. The recirculation potential of this configuration is similar to Configuration 1 and 2.

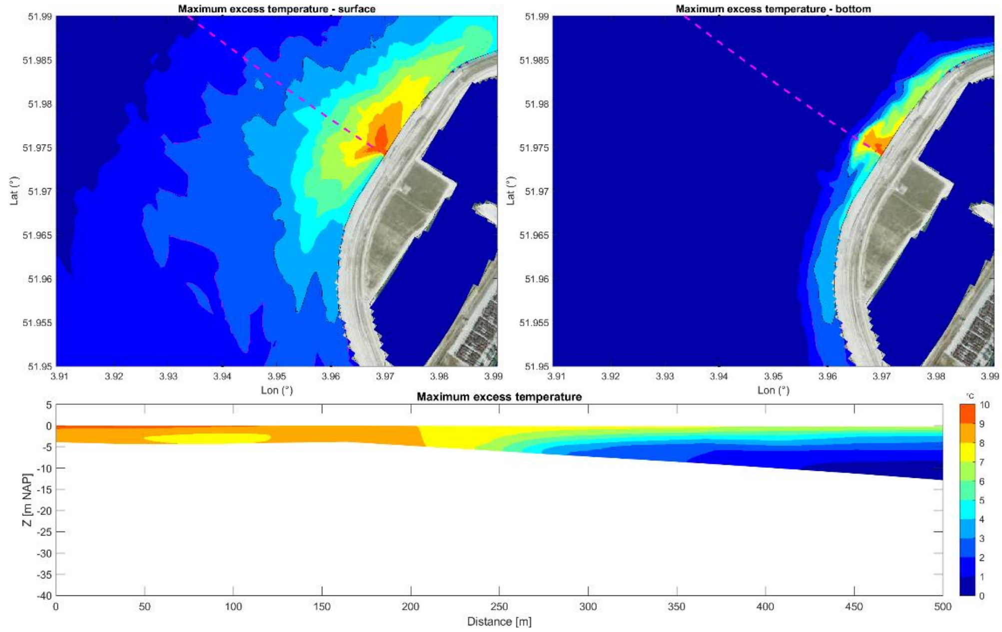

Figure 4.16 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge. Configuration 3.

4.4.1.5 Configuration 4 (Case 7)

Configuration 4 is similar to Configuration 1 but with switched intake and outfall locations. The open intake is now located at the North side of the Maasvlakte area and the open outfall is located in the harbour. This configuration is mainly modelled as a sensitivity scenario to assess the impact of an outfall in the harbour area with respect to the mixing zone criteria. Figure 4.17 and Figure 4.18 show the simulated maximum temperature increase footprint for two different zoom levels.

The results show that the maximum temperature increase due to the open outfall at the harbour area exceeds the 3°C over the full water column. Near the surface, the maximum temperature increase around the outfall is typically up to 10 °C and near the bed the temperature increase is more than 3 °C. The low hydrodynamic conditions in combination with the confined harbour area result in little mixing of the thermal discharge around the outfall and result in a stratified thermal plume in the harbour. When the plume exits the harbour, it disperses along the estuary and towards the North Sea. Due to the stronger hydrodynamic conditions in these areas, the plume rapidly mixes and the temperature increase is reduced to less than 3 °C near the surface and less than 2 °C near the bed.

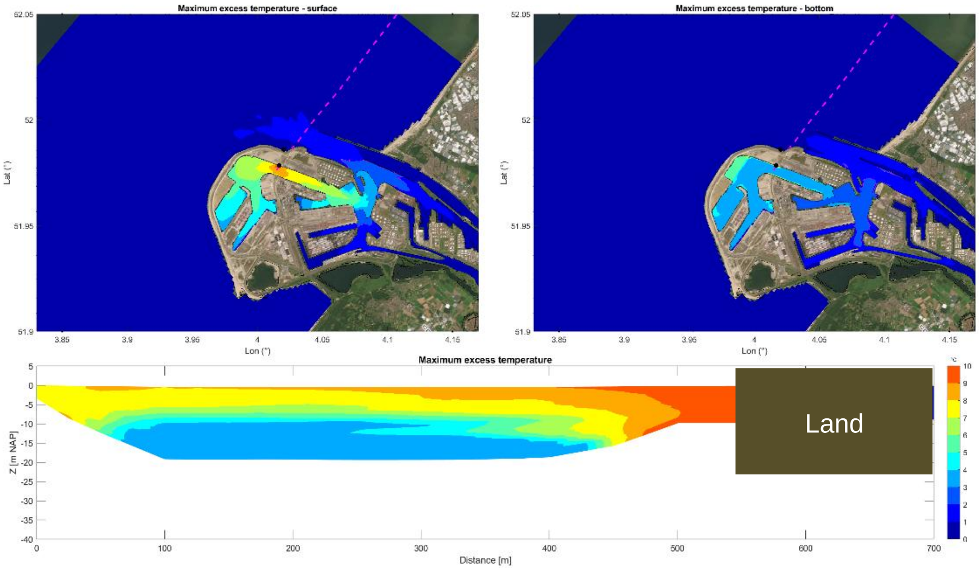

Figure 4.17 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge (Configuration 4).

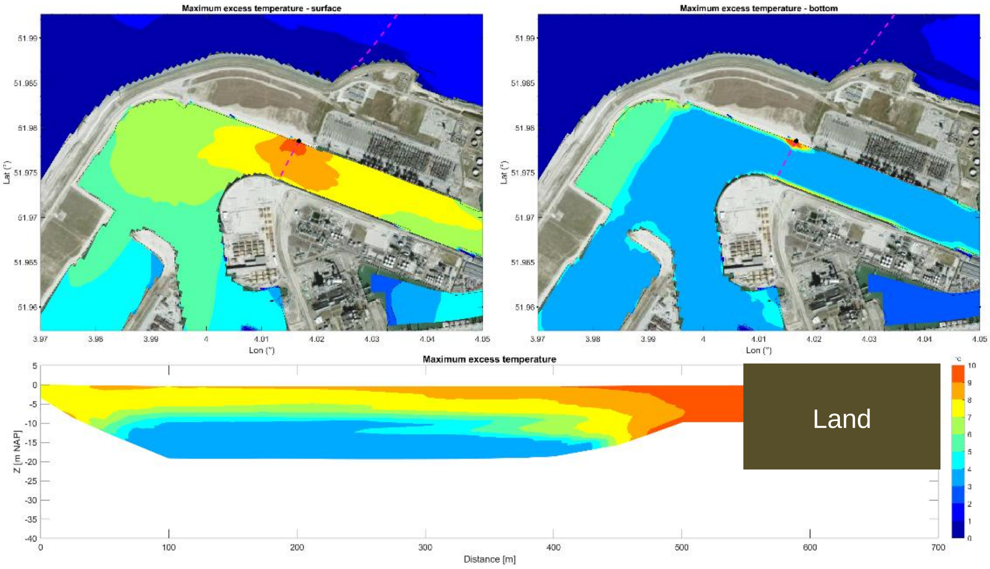

Figure 4.18 Zoomed in simulated maximum temperature increase footprint due to the new Maasvlakte discharge. Configuration 4.

The cross-sectional coverage of the +2 °C covers the entire cross section in the harbour. If the cross section of the Maasmond is considered (separately), the coverage by the +2 °C contour is minimal. However, due to the confined area inside the harbour and the strong temperature increase in that area, this configuration seems infeasible.

The recirculation potential is computed less than 0.1 °C (mean) and 0.6 °C (maximum) for Configuration 4.

4.4.1.6 Configuration 5 (Case 8)

Configuration 5 is similar to Configuration 3, but with the open intake placed at the coast as well (like the outfall), west of the Maasvlakte area. This configuration was simulated to assess the possible recirculation potential of the intake at the west side of an open outfall at a distance of about 1km. Figure 4.19 shows the maximum temperature footprint of Configuration 5.

The results show similar behaviour as Configuration 3. The plume extends along the coast with a temperature increase more than 9°C at the discharge location and over the full water column, due to the shallow depths in combination with the plume thickness. The recirculation potential of Configuration 5 is greater than Configuration 3. The mean and maximum recirculation is computed to about 1.2 °C and 4.3 °C respectively. These higher values are related to the limited mixing of the thermal plume along the coast resulted from the shallow depths in the area in combination with the location of the intake at these shallow depths.

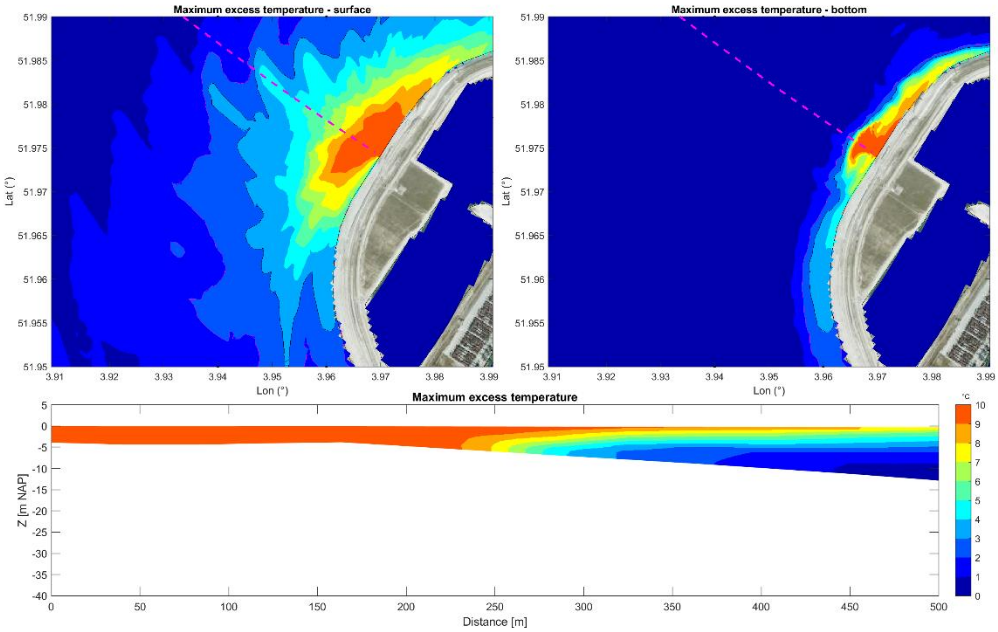

Figure 4.19 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge. Configuration 5.

4.4.1.7 Configuration 6 (Case 9)

In Configuration 6, the open outfall of Configuration 5 is replaced by a submerged outfall at an offshore location in the North Sea. The open intake of this configuration is the same as in Configuration 5. The aim of this scenario is to assess the plume behaviour of a submerged outfall at the North Sea. The diffuser has the same layout as the Configuration 2, but at a different location.

The maximum temperature footprint in Figure 4.20, shows that the cooling water through the submerged outfall in the North Sea area mixes rapidly, resulting in a smaller temperature increase near the outfall. The computed maximum footprint shows an increase in temperature of about 2 °C around the outfall over the full water column. In comparison to Configuration 2, the maximum computed temperature increase near bed does not exceed the 2 °C, mainly due to the larger depths. The recirculation potential of this configuration is limited to less than 0.2 °C mean temperature increase and less than 0.5 °C maximum temperature increase, which is significantly lower than Configuration 5.

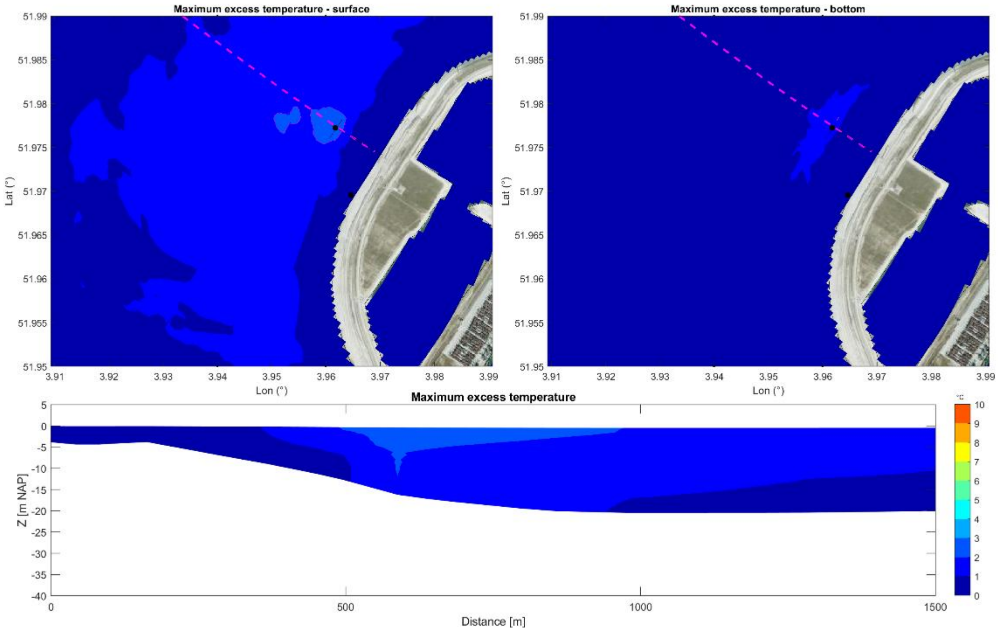

Figure 4.20 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge. Configuration 6.

4.4.2 Different stratification at boundary conditions

The fresh water from the river discharge interacting with the salt water from the sea results in distinct horizontal layering over the water column (stratification). The less dense fresh water can be found at the upper water column and the more dense saline water can be found in the bottom part of the water column. Stratification can influence the vertical mixing and the surface flow velocities, essential for the correct assessment of the plume behaviour and mixing processes of the thermal cooling discharge. To understand the possible influence of different levels of stratification in Maasvlakte area, two additional modelling cases (sensitivity analyses) are assessed for the Configuration 1 layout. Scenario 1 – Case 10, uses the schematized stratification based on the RMM3D model results and expert interpretations to make the stratification stronger, and Scenario 2 – Case 11 assumes a uniform distribution of the freshwater discharge over the water column from the river boundary of the model (i.e., making the stratification weaker).

Figure 4.21 shows the results of Case 1 used in the present assessment. Figure 4.22 and Figure 4.23 show the results of the sensitivity scenarios Case 10 and Case 11 respectively. The maximum excess temperature footprints show no significant differences between the different cases. It can therefore be concluded that the plume dispersion results are not sensitive to the level of stratification (at the river boundaries), which is a model input with some uncertainty. This will therefore however not influence the conclusions of the present study.

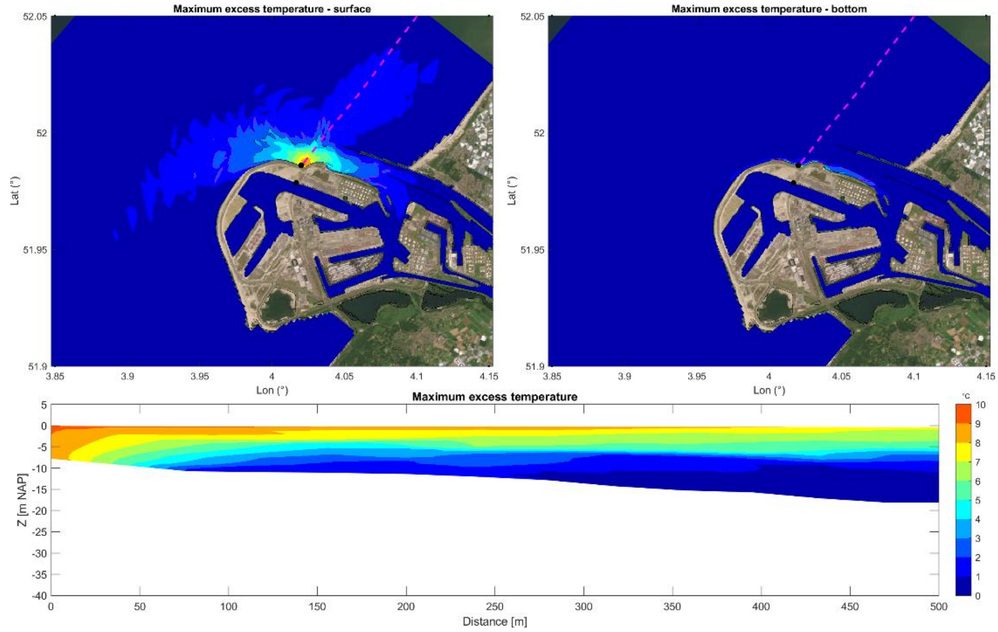

Figure 4.21 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge for Case 1, Configuration 1.

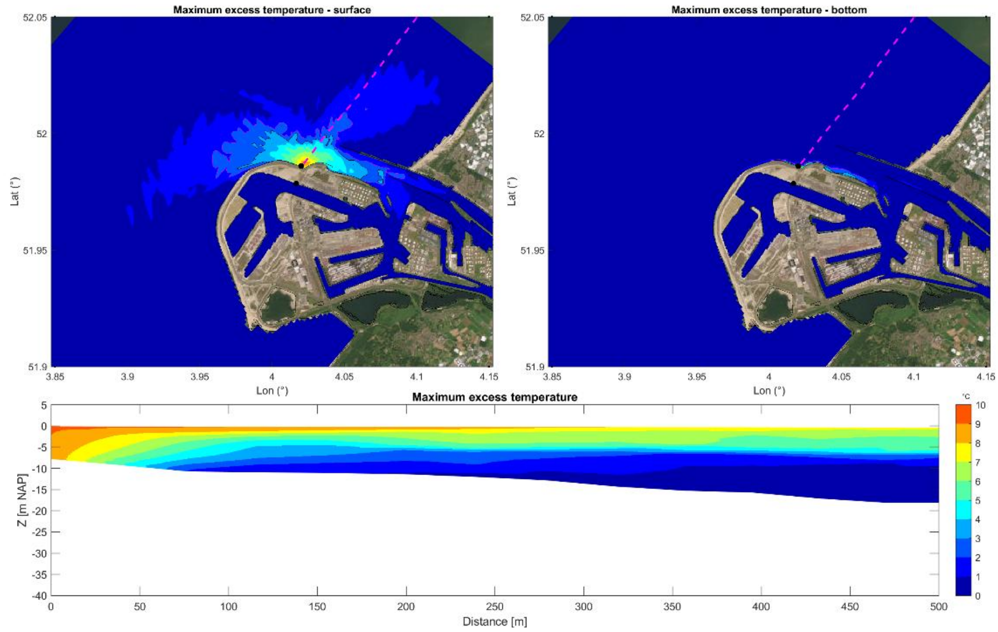

Figure 4.22 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge for Case 10, Configuration 1.

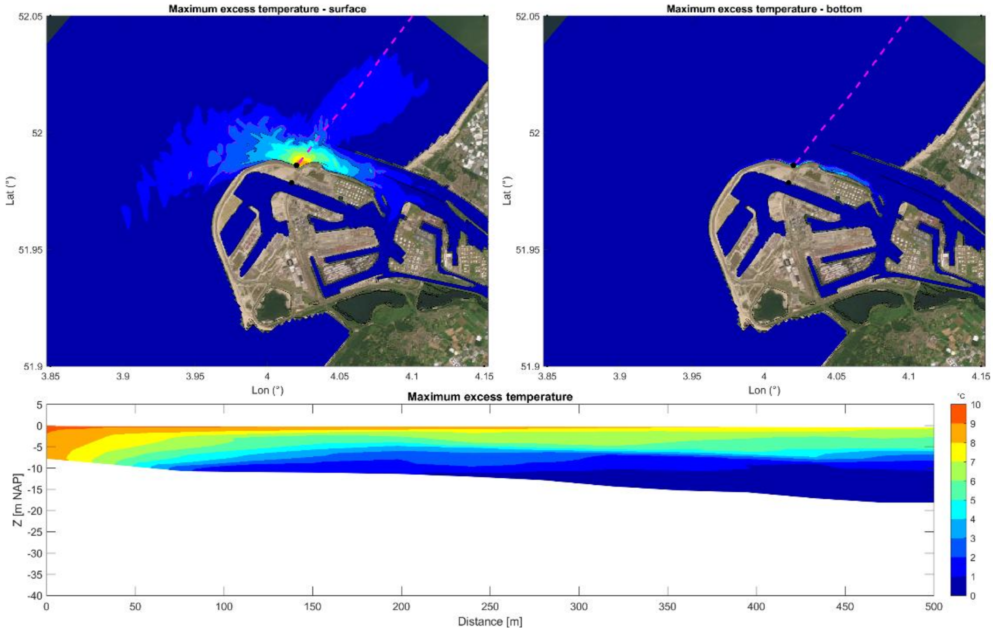

Figure 4.23 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge for Case 11, Configuration 1.

4.4.3 Different discharge characteristics

Next to the type and location of the Maasvlakte intake and outfall, the discharge characteristics (i.e., discharge flow and temperature increase between intake and outfall) are important design parameters for operational conditions of the plant and the potential effects on the environment. For a certain thermal load, a higher temperature over the condenser results in a lower discharge flow and vice versa. A cooling water system with a lower flow is beneficial for e.g., the pump capacity needed, dimensions of the intake and outfall, the head losses in the system and ecological impingement into the intake. However, a discharge with a higher temperature increase also needs a higher mixing to limit the water temperature increase around the outfall.

To assess the impact of the discharge characteristics, simulations were performed with different discharge flow and temperature increase combinations. All these simulations have the same thermal load of 6000 MW. Both an open outfall and a submerged outfall were simulated.

4.4.3.1 Open outfall, Configuration 1

Simulations were performed with different discharge characteristics for intake and outfall Configuration 1 with a temperature increase of +7 °C, +9 °C and +12 °C, with respectively flow rates of 205 m^3/s, 159.5 m^3/s and 119.5 m^3/s. Figure 4.24 - Figure 4.26 show the maximum simulated temperature increase at for Discharge option 1 (+7°C), Discharge option 2 (+9°C) and Discharge option 3 (+12°C) respectively. Figure 4.25 shows the maximum temperature increase for Discharge option 2 (+9°C) but is repeated here for easy reference.

These figures show the effect of the Maasvlakte discharge characteristics on the maximum temperature increase around the outfall. The open outfall has limited mixing in the shallow areas. In the first hundreds of meters from the outfall, the outfall plume experiences little mixing and the temperature increase around the outfall rises up to the temperature at the outfall itself. The near bed maximum excess temperature of less than +2 °C is computed at 100 meters from the discharge location for Discharge option 1 because of the thicker plume. For Discharge Option 2 and Option 3 the near-bed +2 °C contour is computed at a smaller distance of 85m from the discharge location. Further away from the outfall, the discharge cooling water rapidly mixes, and little differences are computed in the temperature increase for the different options. Hence, the +1 °C maximum temperature increase contour is the same for all cases. For Configuration 1, no significant impact of the discharge characteristics on recirculation is computed.

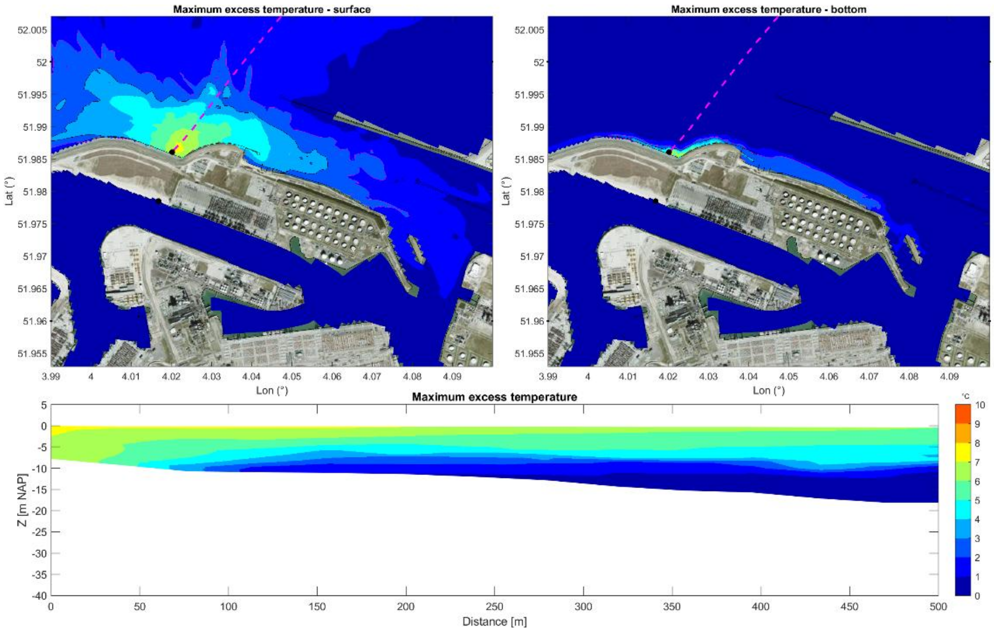

Figure 4.24 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge with a temperature increase of +7 °C.

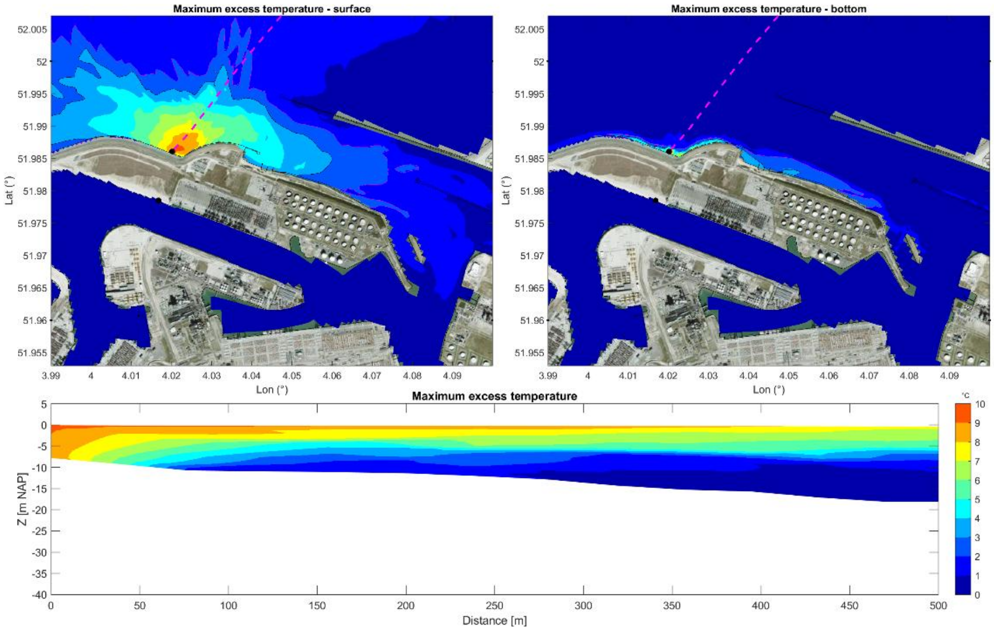

Figure 4.25 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge with a temperature increase of +9 °C (original case).

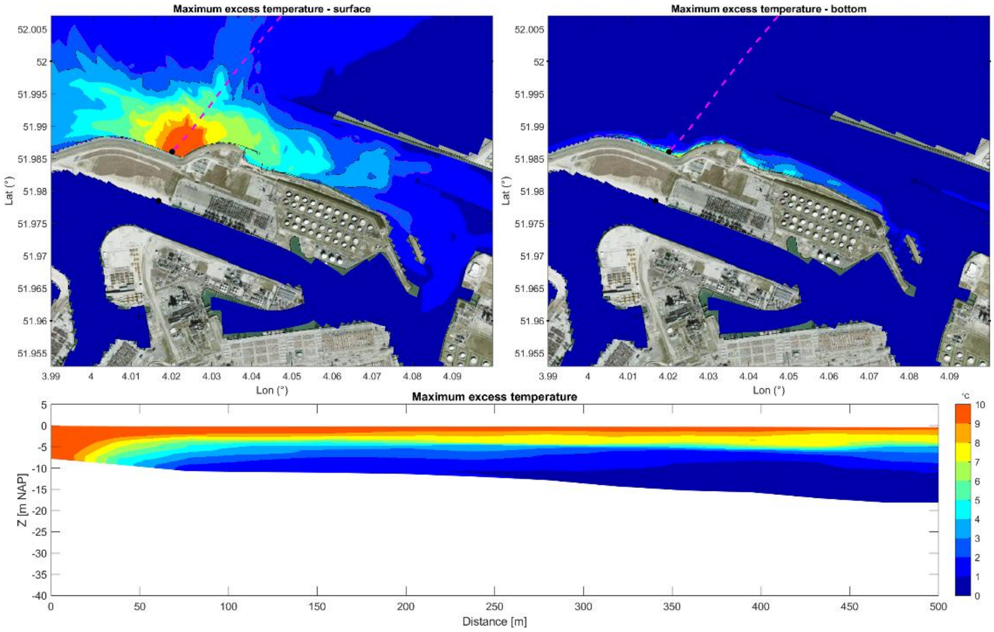

Figure 4.26 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge with a temperature increase of +12 °C.

Figure 4.27 - Figure 4.29 show the percentage of the cross-sectional area covered by the mixing zone and the average temperature over the cross-sections in the Maasmond area (estuary entrance) for Configuration 1 with a temperature increase of +7 °C, +9 °C and +12 °C respectively. The maximum percentage covered by the mixing zone ranges between 20-23% (T>2°C) for these modelled cases. It is noted that these percentages are close to the environmental temperature criterion of maximum 25% of the cross section covered by the mixing zone.

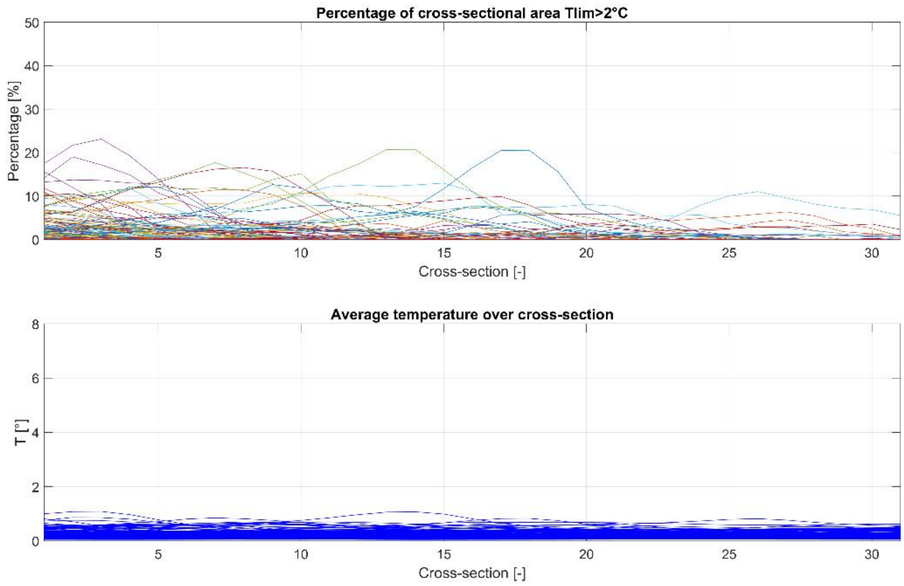

Figure 4.27 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area). Configuration 1 with a temperature increase of +7 °C.

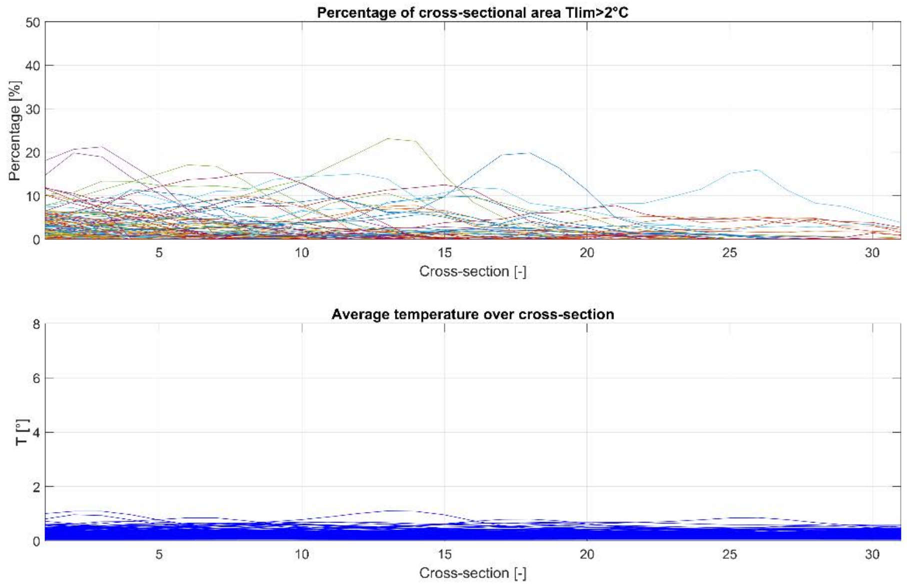

Figure 4.28 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area). Configuration 1 with a temperature increase of +9 °C.

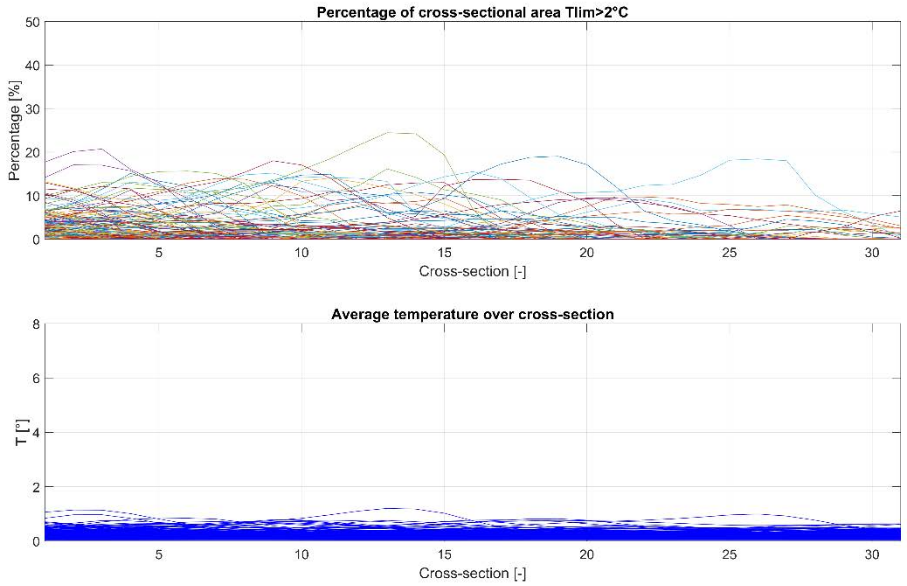

Figure 4.29 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area). Configuration 1 with a temperature increase of +12 °C.

4.4.3.2 Submerged outfall, Configurations 2 and 6

Similar simulations were performed with varying discharge characteristics for Configuration 2 and 6, both with a submerged outfall for the Maasvlakte discharge. A different discharge flow could result in a different indicative diffuser layout, i.e., with a lower exit velocity of the diffuser, fewer ports to discharge or smaller port diameters. In this assessment it was chosen to reduce the port size and keep a similar exit velocity at the diffuser port (and with that a similar near field dilution). Only Discharge option 3 (+12 °C) was considered since the main benefit of a submerged diffuser outfall is to achieve high mixing rapidly and close to the outfall. Diffusers are less efficient in discharging high volumes of cooling water with a lower temperature increase.

Figure 4.30 shows the maximum temperature increase footprint for Configuration 2 and Discharge option 3. Compared to Discharge option 2 (Figure 4.31), the original simulation (+9 °C), the maximum temperature footprint shows that Discharge option 3 can lead to a larger plume extent than Discharge option 2. Discharge option 3 can lead to a higher maximum temperature increase near the bed at shallow depths, by approximately 1°C. Figure 4.32 and Figure 4.33 show the Discharge Option 3 and Discharge Option 2 for Configuration 6 respectively. Contrary to Configuration 2, Configuration 6 does not show an increase in temperature near the bed at the shallower depths. Due to the larger depth compared to the outfall location in Configuration 2, the outfall plume stratifies somewhat more strongly in the +12 °C outfall option than in the +9 °C option. The higher discharge temperature results in slightly higher temperatures at the surface, more buoyancy and therefore lower temperatures near the bed around the diffuser compared to the +9 °C case. The recirculation potential did not change for the simulated discharge options.

From these simulations it can be concluded that higher discharge temperatures and lower discharge flow rates for the Maasvlakte discharge do not result in a substantially different plume behaviour. Depending on the location (mainly depth and local flow patterns), the near-bed temperature increase could either reduce or slightly increase. It is therefore necessary to consider the outfall location and diffuser layout in more detail when a higher discharge temperature is considered.

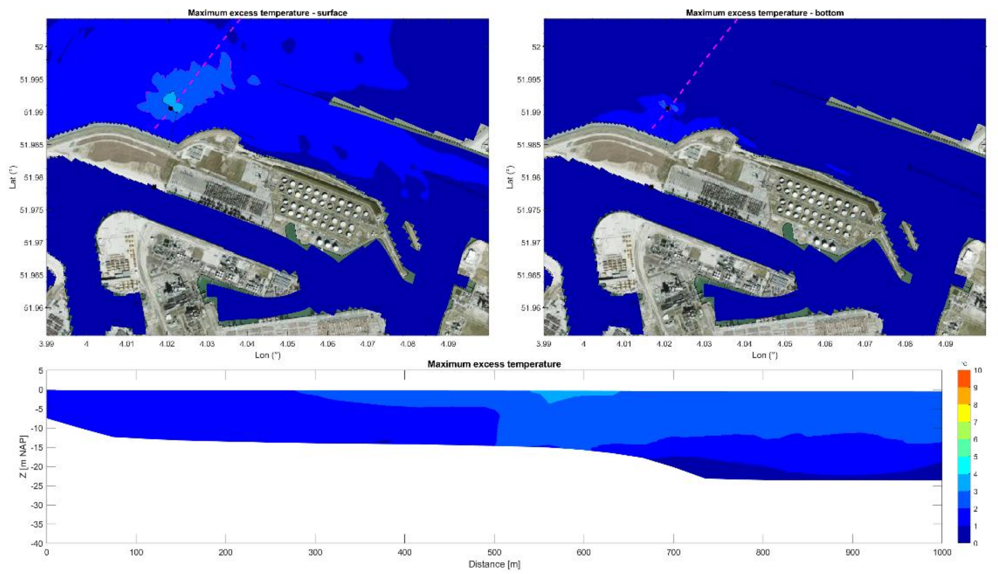

Figure 4.30 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge with a temperature increase of +12 °C.

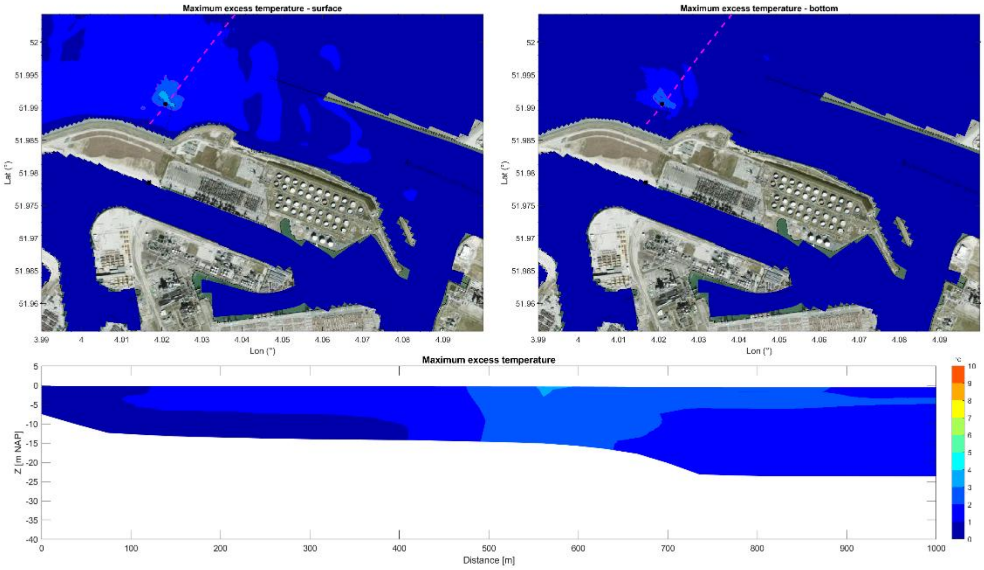

Figure 4.31 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge with a temperature increase of +9 °C (original simulation).

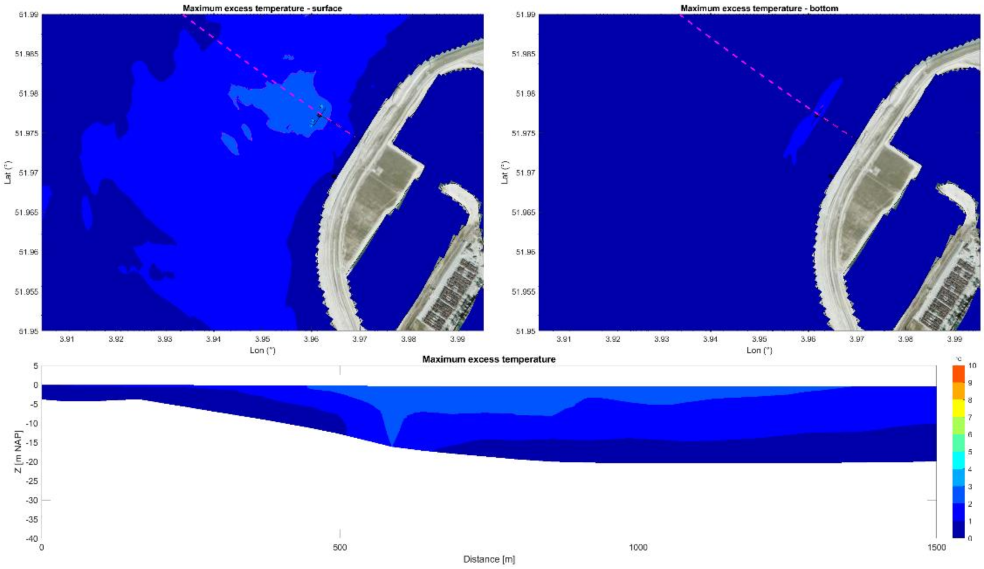

Figure 4.32 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge with a temperature increase of +12 °C.

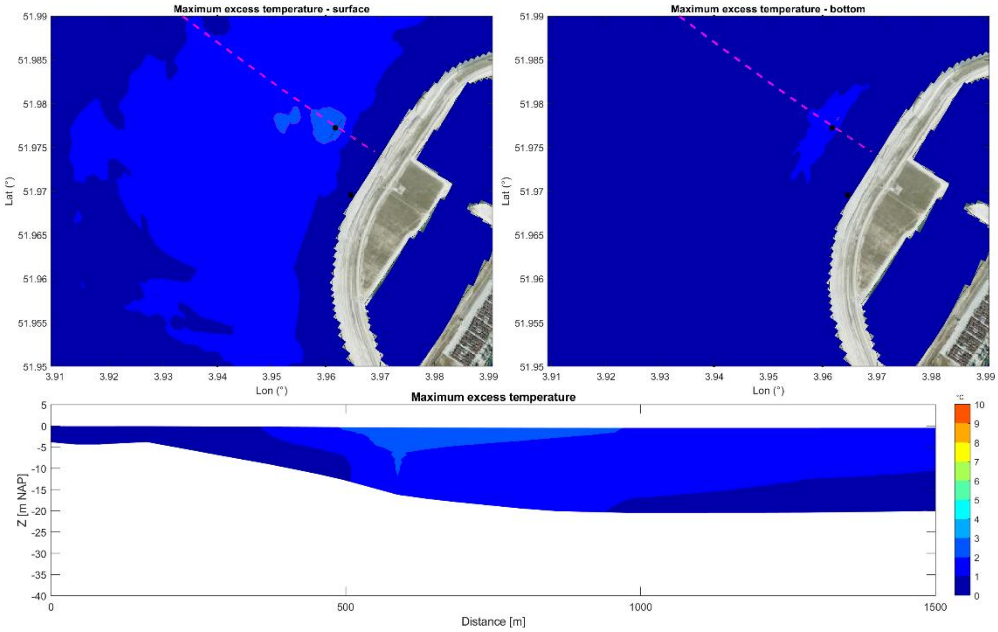

Figure 4.33 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge with a temperature increase of +9 °C (original simulation).

4.4.4 Thermal discharge capacity

Additionally, a sensitivity simulation was performed with a decreased thermal discharge capacity to assess the effect of a lower thermal discharge on the plume dispersion and mixing. For this simulation, the thermal discharge capacity was reduced from 6000 MW to 4000 MW. To achieve this reduction, the discharge flow was reduced by 1/3 from 159.5 m^3/s to 106.3 m^3/s with the same temperature increase between intake and outfall (+9 °C).

The reduced thermal discharge capacity was assessed for Configuration 1. Figure 4.34 shows the simulated results for this sensitivity test. For comparison, Figure 4.35 shows the results again for the full thermal capacity of a 6000 MW thermal discharge for easy comparison.

Figure 4.34 shows that the temperature increase around the outfall typically decreases with lower thermal discharges. For the 4000 MW case, the +1 °C maximum temperature increase contour at the surface is about 11 km in alongshore direction (compared to almost 16 km for the 6000 MW case). The effect of a lower thermal discharge capacity is less pronounced for the increase in temperature in shallow areas, near the outfall. The temperature in shallow areas around the open outfall is mainly determined by the discharged temperature as these areas are saturated by the outfall discharge. Therefore, smaller differences in temperature increase are found between the two cases closer to the outfall.

For the reduced discharge capacity, the maximum percentage of the cross-sectional area covered by the mixing zone is about 18% in Maasmond area, see Figure 4.36, which is 4-5% lower than the simulated percentages with the full thermal discharge capacity, see Figure 4.37. The mean and maximum computed recirculation due to the lower thermal discharge capacity remains the same as the full thermal discharge capacity.

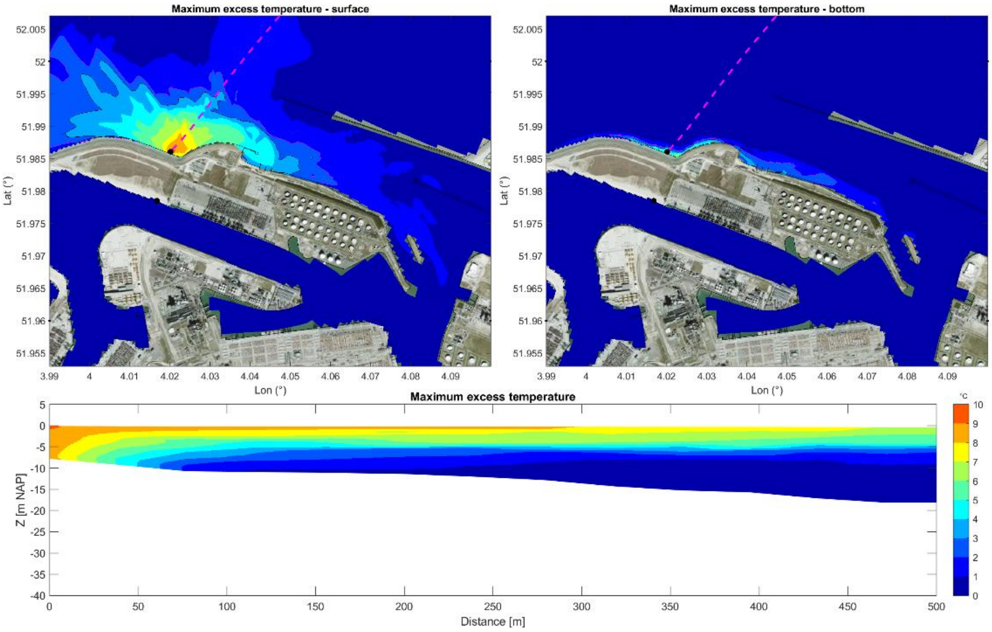

Figure 4.34 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge for 4000 MW_{th}.

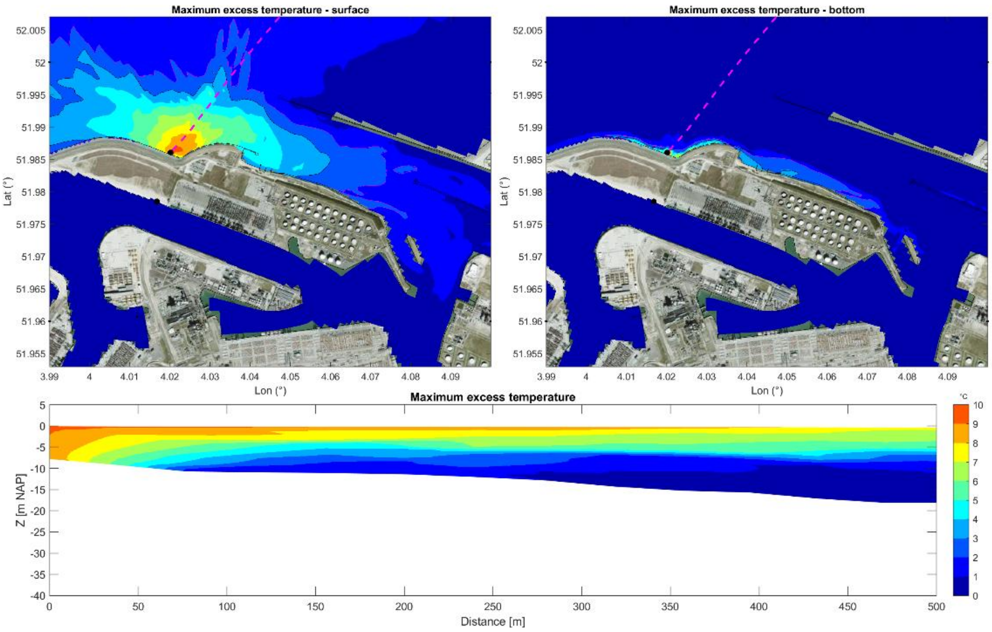

Figure 4.35 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge for 6000 MW_{th} (original simulation).

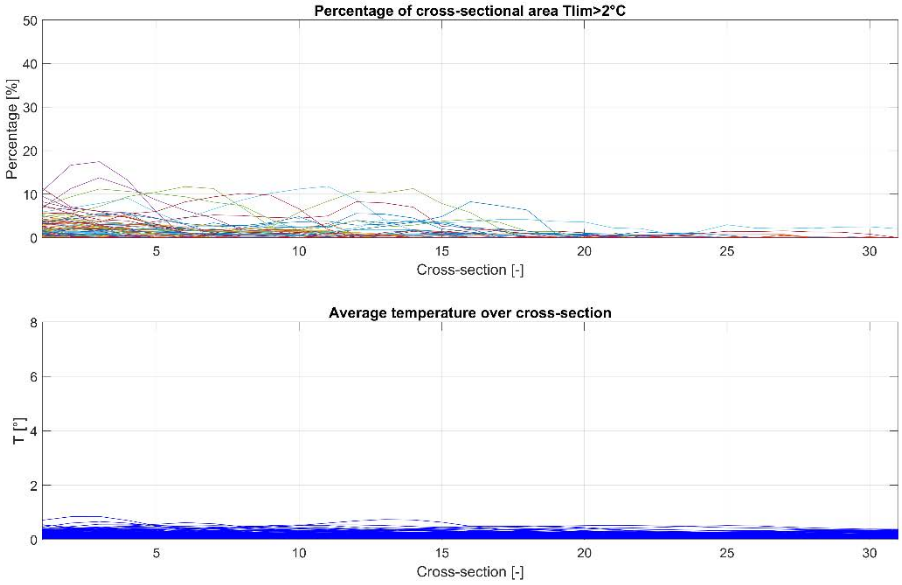

Figure 4.36 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) for 4000 MW_{th}.

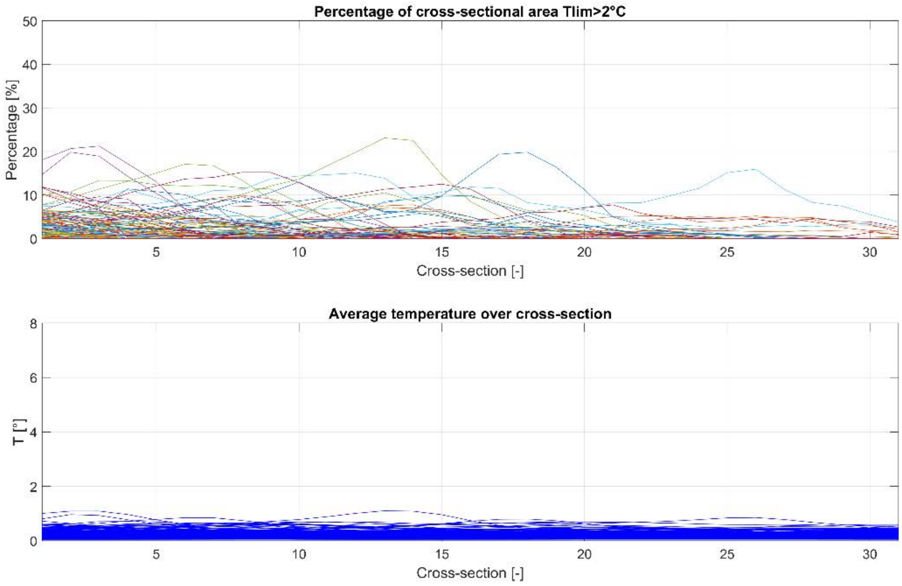

Figure 4.37 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) for 6000 MW_{th} (original simulation).

4.4.5 Additional breakwaters (Case 14)

The open outfall option for the Maasvlakte discharges in rather shallow water resulting in relatively limited mixing therefore a substantial temperature increase near the bed over a relatively large area around the outfall. In attempt to mitigate this, structures like breakwaters could be considered to deflect the outfall plume further to deeper water. In this deeper water, the outfall plume could stratify and rise to the surface (i.e., reduce the near-bed temperature increase) and mix more efficiently due to the higher (tidal) flow conditions further offshore. If furthermore the breakwaters could be considered part of the outfall structure, this could help with meeting the environmental temperature regulations outside of the outfall.

To assess the impact of a breakwater on the plume dispersion and mixing, a simulation was performed for Configuration 1 (called Configuration 1b) that includes breakwater structures around the open outfall, see Section 2.6.2. The simulation was carried out for the discharge option with a temperature increase of +12 °C. The breakwater extends to -11 m NAP, after which the bathymetry has a mild sloping bed. These breakwaters are initial suggestions for mitigation and the design should be carefully considered in relation to other aspects in terms of feasibility and stability with the (strong) tidal currents. These considerations are not included in the present study. Model results for Configuration 1b are presented in Figure 4.38 and Figure 4.39.

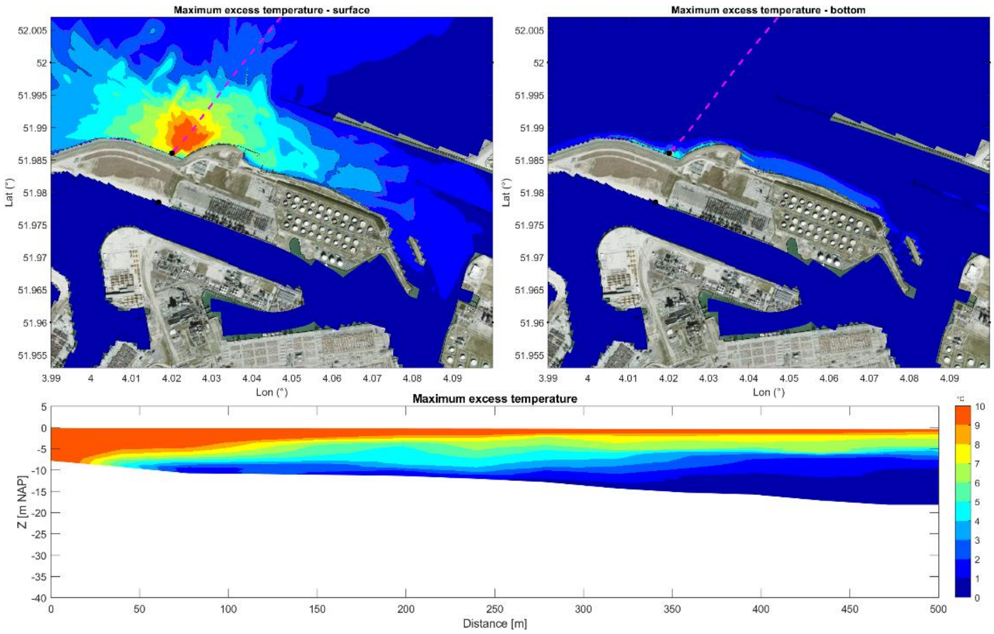

Figure 4.38 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge for Case 14, Configuration 1b (Discharge option +12 °C).

Figure 4.38 shows that with presently used breakwater configuration (of about 250m length) does not reduce the near-bed temperature increase around the outfall. Possibly a substantially longer breakwater structure might reduce the near-bed temperature increase near the open outfall, but this will likely have cost and marine implications. Figure 4.39 shows that breakwaters result in similar results related to the percentage coverage of the cross-sectional area by the mixing zone and the average temperature increase as Configuration 1 (and similarly close to the 25% environmental temperature criterion for the mixing zone cross section coverage).

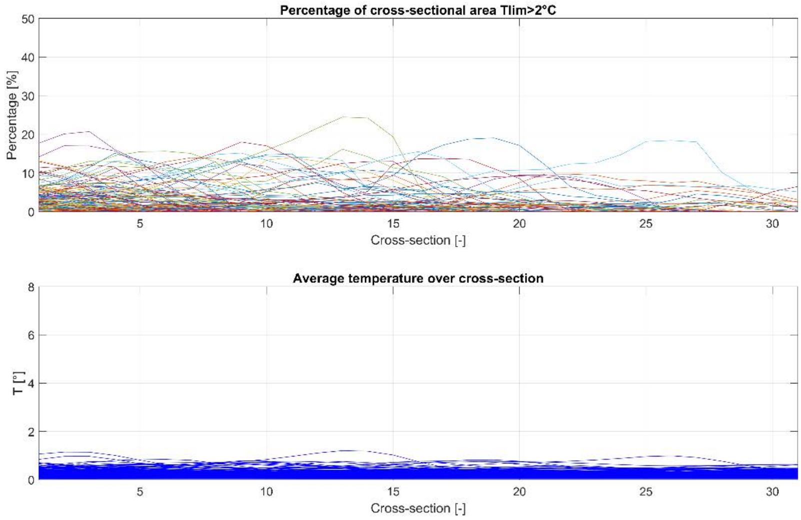

Figure 4.39 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area). Configuration 1b, Case 14 (Discharge option +12 °C).

4.4.6 Possible impact of existing intake and outfalls

As mentioned in Section 2.5, the present study was done without the effects of existing intake and outfall structures in Maasvlakte area. This is due to the unavailability of data for the location and discharges of the existing plants at the time of this study. To anyway make a first assessment of the potential influence of the existing plants in the Maasvlakte, a sensitivity analysis was carried out. The effect of existing intake and outfalls in the area was assessed by adding +1 and +2 °C to the background temperature at the intake location. These additional temperatures are a first estimate to represent elevated background temperatures due to other operations in the harbour area. These increased intake temperatures are applied to the intake only (and are subsequently discharged), but the overall background temperature in the model is not increased, so that an assessment can be made on the possible effects of the combination of different operations.

Figure 4.40, Figure 4.41 and Figure 4.42 show the resulting maximum excess temperature of Case 1 (T_{intake} = <+0.2 °C, assuming no concurrent operating plants), Case 12 (T_{intake} = +1 °C) and Case 13 (T_{intake} = +2 °C) respectively. The maximum excess temperature footprints show that the increase in intake temperature due to any existing plants results in increased excess temperature at the discharge location. The maximum excess surface temperature of 2 and 3 °C contour extends about 1-1.5km further along the shore. The extent of the near-bed +2 °C contour does not significantly change between the different cases. The maximum percentage cross sectional coverage area in Maasmond area increases by 4-6% when an increase in the intake temperature is assumed, see Figure 4.43 - Figure 4.45. In these cases it is noted that these percentages could even exceed the environmental temperature criterion of maximum 25% of the cross section covered by the mixing zone. Furthermore, aside from the simulated (ambient) conditions, other conditions may (temporarily) occur that could increase this percentage somewhat further. It is therefore advised to carefully consider this intake and outfall configuration in more detail, since the feasibility from an environmental temperature point of view is not obvious. The averaged cross-sectional temperature remains the same for all cases.

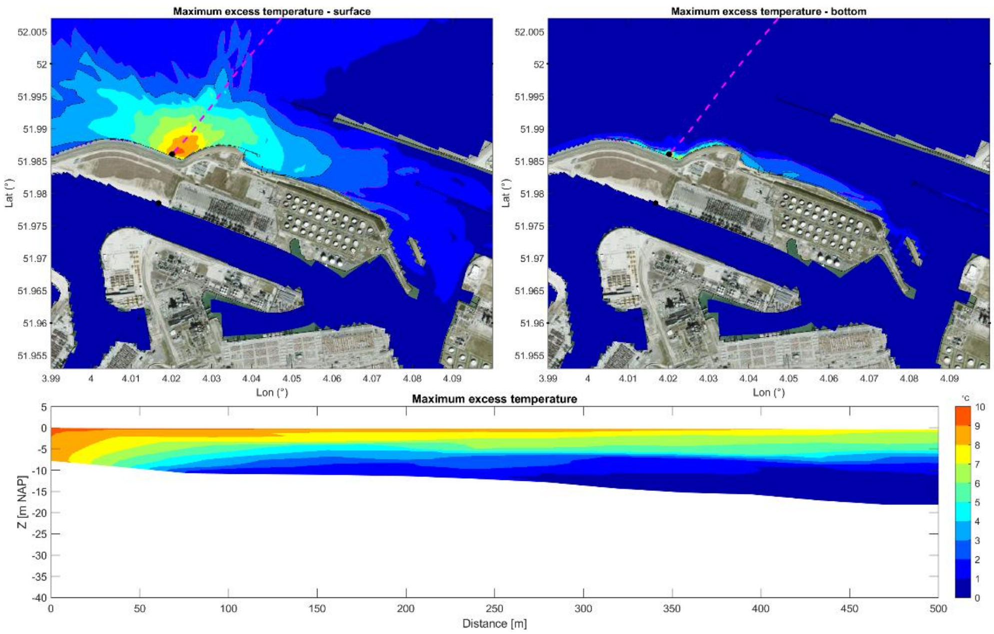

Figure 4.40 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge for Case 1, assuming no other operating plants.

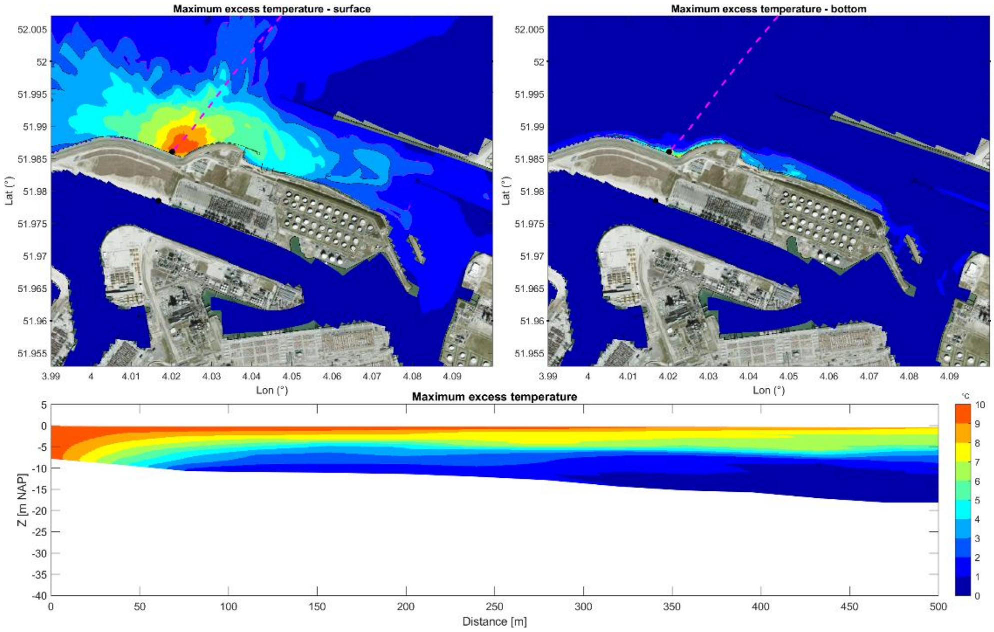

Figure 4.41 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge for Case 12, assuming an increased intake temperature of +1 °C.

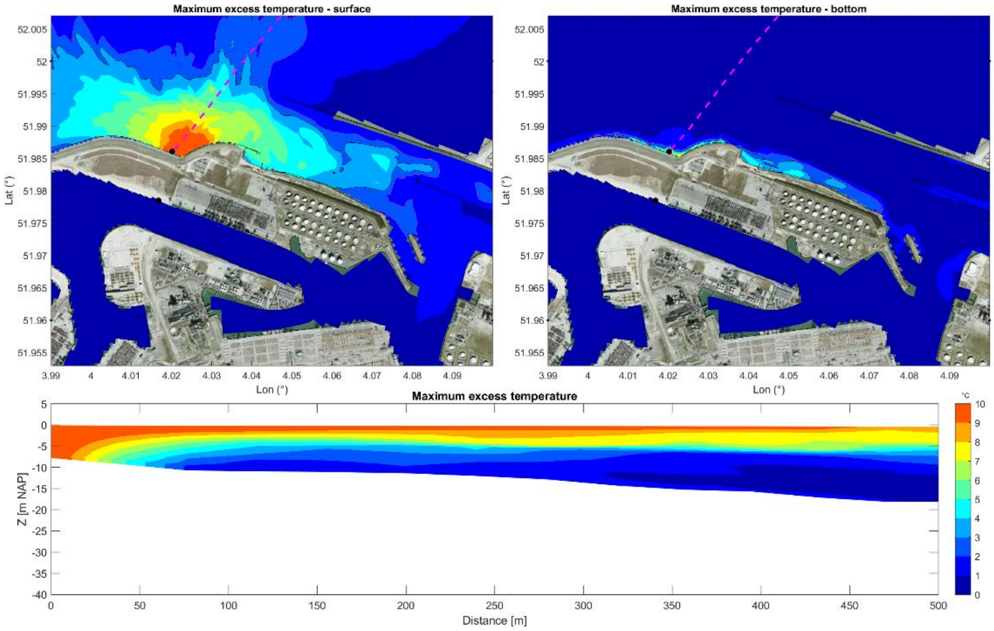

Figure 4.42 Simulated maximum temperature increase footprint due to the new Maasvlakte discharge for Case 13, assuming an increased intake temperature of +2 °C.

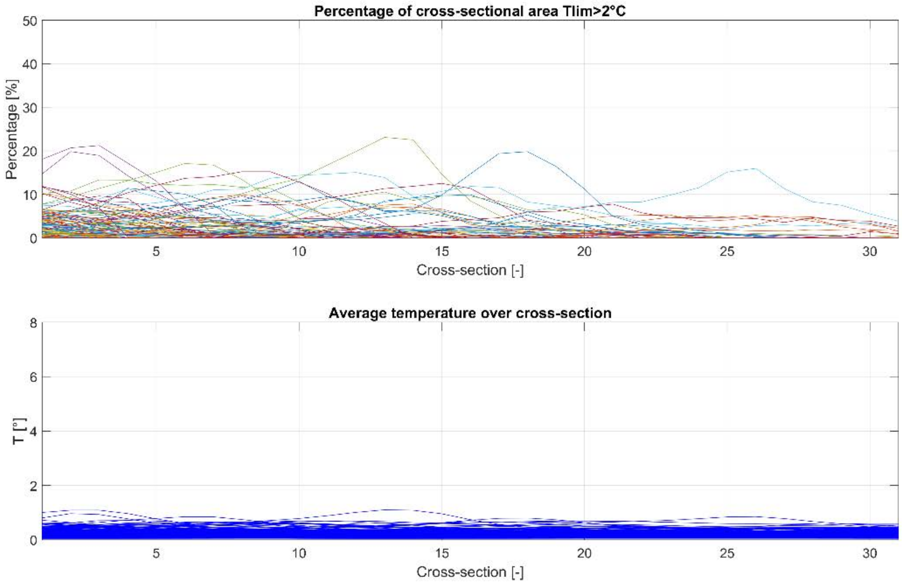

Figure 4.43 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond), assuming no other operating plants.

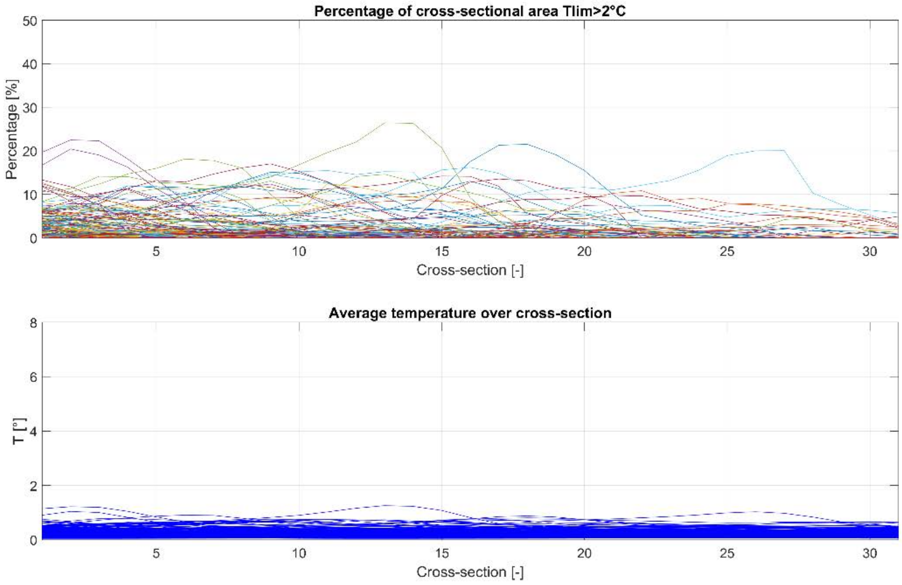

Figure 4.44 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond), assuming an increased intake temperature of +1 °C.

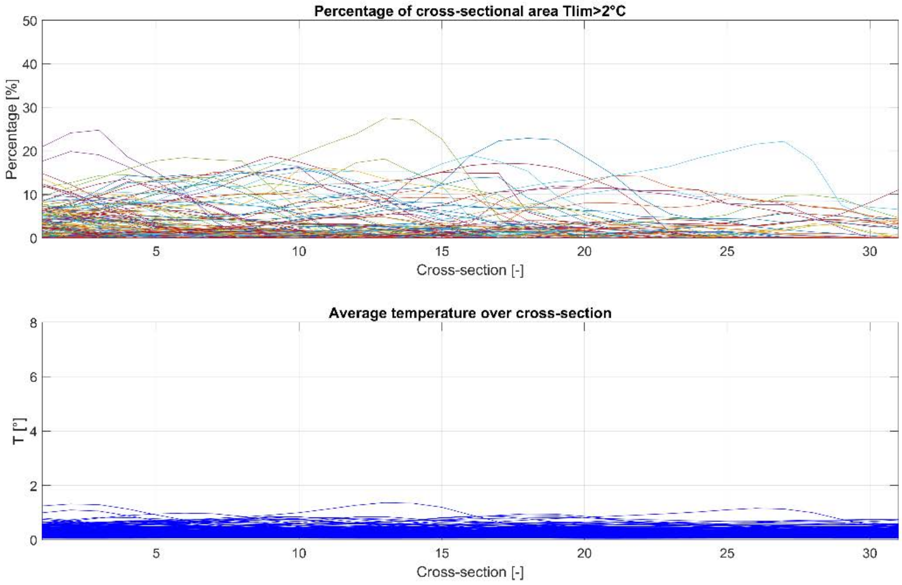

Figure 4.45 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond), assuming an increased intake temperature of +2 °C.

5 Conclusions

The Dutch government is considering developing two new large nuclear power plants in the Netherlands and has selected nine possible sites at Sloegebied (Borssele), Terneuzen, Eemshaven and the 2e Maasvlakte as the possible locations for this. Similar to Borssele, Deltares was requested by EZK to perform, amongst others, a detailed modelling study on the availability of cooling water at the 2e Maasvlakte. This will provide initial technical information to possible vendors (i.e., developers) which need to carry out their own technical studies towards an initial design of such a plant.

The objective of this cooling water study is to assess the cooling water availability/capacity in the Maasvlakte area. Specifically, assess the plume dispersion and recirculation of the new Maasvlakte cooling water discharge in relation to the applicable environmental criteria for different intake and outfall options (Deltares, 2023). The studies carried out are not intended to be complete and are therefore not a guarantee that if the developers follow the information provided, this will entitle them to a permit and acceptance of the development. It is further noted that the authorities have indicated that water quality and ecology are also important aspects in relation to the feasibility of the development of nuclear power plants and that these aspects have not yet been included in this first, exploratory study.

The objective was studied by means of a hydrodynamic Delft3D model that simulates the dispersion of the Maasvlakte cooling water discharge. This (detailed) model was set up around the Maasvlakte project area and nested in the in-house available Rhine-Meuse estuary model. When submerged outfalls were considered, the Delft3D model was dynamically coupled to a database of near-field results of CORMIX. With this coupled modelling system different intake and outfall configurations, plant capacities, discharge characteristics and additional structures were simulated under various ambient conditions relevant for the applicable environmental temperature criteria and forcings that effect the plume dispersion.

The main information and results are summarised below and based on this, the following main conclusions are drawn:

Project information

- For the present first assessment of different Maasvlakte cooling water configurations only the CIW 2004 (temperature) mixing zone and average temperature increase criteria were used. It is noted that compliance with possible other criteria (e.g., on other water parameters) would need to be evaluated in a full environmental impact assessment study in a next phase of the project. For a complete overview of the environmental criteria, see Deltares (2023).
- The 98th-percentile ambient background temperature relevant for the CIW 2004 criteria at the edge of the water body (Botlek) is 22.96 °C. The 98th-percentile ambient temperature at the project site itself is estimated 22 °C (Hoek van Holland).
- No detailed designs or discharge characteristics were available at the start of this assessment. Therefore, together with EZK, different cooling water discharge characteristics and intake and outfall options for the Maasvlakte plant were selected.
- The existing intake and outfalls are not implemented in this modelling study due to unavailability of data. Therefore, only the new development is assessed, which follows the objective of the study. It is noted however that the operation of existing intakes and outfalls could have an effect on the operation and possibly feasibility of the intake and outfall configurations for the nuclear power plant assessed in this

study and in a next phase of the project, these should be considered. For the present initial phase of the project, the assessment without the existing operations is nevertheless deemed representative.

- For the present modelling assessment on the Maasvlakte cooling water system, 7 different intake and outfall configurations were considered. These configurations include variations in the location of the intake and outfall, the type of intake and outfall structure (open or submerged) and additional structures (breakwaters). Furthermore, variations in the thermal discharge capacity and discharge characteristics were simulated.
- A maximum thermal discharge capacity of the Maasvlakte cooling water system of 6000 MW_{th} was selected. For this capacity, 3 different combinations of flow rate and temperature increase between the intake and the outfall were assessed: a discharge of 205 m^3/s and a temperature increase of +7°C, a discharge of 159.5 m^3/s and a temperature increase of +9°C and a discharge of 119.5 m^3/s and a temperature increase of +12°C.
- An overview of the simulated scenarios is presented in the below table.

Case	Thermal Capacity	Discharge option/Cooling water temperature increase	Background temperature	River discharge	Configuration	Modified parameters
0	-	-	98th- percentile	Low	-	-
1	6000	2/+9°C	98th- percentile	Low	1	-
2	4000	2/+9°C	98th- percentile	Low	1	-
3	6000	1/+7°C	98th- percentile	Low	1	-
4	6000	3/+12°C	98th- percentile	Low	1	-
5	6000	2/+9°C	98th- percentile	Low	2	-
5b	6000	3/+12°C	98th- percentile	Low	2	-
6	6000	2/+9°C	98th- percentile	Low	3	-
7	6000	2/+9°C	98th- percentile	Low	4	-
8	6000	2/+9°C	98th- percentile	Low	5	-
9	6000	2/+9°C	98th- percentile	Low	6	-
9b	6000	3/+12°C	98th- percentile	Low	6	-
10	6000	2/+9°C	98th- percentile	Low	1	Modified salinity at the riverine boundary
11	6000	2/+9°C	98th- percentile	Low	1	Uniform salinity at the riverine boundary
12	6000	2/+10°C	98th- percentile	Low	1	Additional excess heat
13	6000	2/+11°C	98th- percentile	Low	1	Additional excess heat
14	6000	3/+12°C	98th- percentile	Low	1	Including breakwater structures

Model setup:

- A dedicated three-dimensional model was setup in Delft3D 4 for the Maasvlakte area. Hydrodynamic boundary conditions for this detailed model were derived from available and validated overall Rhine-Meuse estuary model.
- The detailed Delft3D model was verified against the results of the validated Rhine-Meuse estuary model to ensure that the model provides accurate results.
- The near-field behaviour of a submerged outfall thermal plume was assessed by means of the CORMIX expert system. CORMIX computes the hydrodynamic behaviour of the outfall plume close the outfall including the plume trajectory and dilution. The results of the near field assessment are subsequently coupled to the far field model with use of Deltares' C-SUMO (Coupled Subgrid Model) system.

Modelling results of the Maasvlakte intakes and outfalls:

- The model results were compared to the applicable CIW 2004 thermal environmental criteria. For the Maasvlakte estuary area, the mixing zone is defined by the 25°C temperature contour. The maximum mixing zone should be less than 25% of the cross section of the water way. For the North Sea, the mixing zone (i.e., the 25°C contour) should not reach the seabed. Furthermore, the average temperature of the water body may not increase by more than 2°C and/or increase above 25°C.
  It is noted that only thermal criteria were assessed in this initial study and no other, possibly applicable criteria related to e.g., ecology (as part of the KRW guidelines) were assessed in this study. These need to be considered in a next phase of the project.
- The present modelling study has shown that all modelled cases result in limited average temperature increase at the estuary area. The average temperature increase due to the outfall discharge is less than the +2 °C criterion.
- All open outfall options will result in high temperature increase near the bed at the first hundred meters from the discharge location. Due to high discharge flow rates in combination with the limited local depths, the results show that there is limited initial mixing on the first tens of meters and a high temperature increase, up to 10°C, compared to background temperatures near the bed. Further away, up to hundred meters from the discharge location, the outfall plume stratifies and rises to the surface.
- For Configuration 1 and all discharge cases, the 2 °C excess temperature contour (i.e., 25 °C contour) touches the bottom over a length of about 100m. Further to the east of the discharge location and close to the coast, the temperature increase near the bed by 2 °C extends to a maximum distance of 350m from the coastline.
- Placing the outfall in the harbour area, e.g., Configuration 4, will result in an initially vertically mixed plume with a high temperature increase. Due to the confined area in the harbour and the limited flow circulation, the entire cross-sectional area at the outfall in the harbour increases temperature with 2 °C or more.
- For an outfall at the west side of the Maasvlakte area (e.g., Configuration 5), the 2 °C excess temperature contour can reach the bottom at a distance of 350 m from the outfall due to the shallow depths along the shore.
- To reduce the increase in (bottom) temperatures around the outfall, a submerged outfall diffuser is considered.
- A submerged outfall diffuser option showed that the discharged cooling water with the ambient water mixes rapidly over the water column. The results showed that such submerged outfall diffuser can prevent temperatures near the bed to increase above 25 °C (i.e., +2 °C) for several configurations, but that with higher cooling water temperatures (i.e., different discharge options), near-bed temperatures could still be high. It is therefore advised to carefully assess the outfall location and diffuser layout in more detail when a higher discharge temperature is considered.
- The mean temperature increase (i.e., recirculation due to the discharged cooling water) at the different intake location options is computed to be less than +0.1 °C for all configurations, i.e., very limited. The exception is the configuration with an open outfall

and open intake at the west side (Configuration 5), which reaches a mean recirculation of +1.2 °C.

The above conclusions are based on a limited number of layout options and simulations for the Maasvlakte cooling water system in this initial modelling assessment. Further development and optimization of the intake and outfall configurations and operation should be considered in the next phase of the project. Furthermore, the present assessment only focusses on the temperature effects of the cooling water discharge for the Maasvlakte area. Possible other (environmental) criteria and design aspects should also be considered that could influence the eventual design choices for the Maasvlakte cooling water system. The results of these studies (and follow-up studies by the developers) must be compared with and, if necessary, adapted to the data from the KNMI's updated climate scenarios of October 2023.

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A Recirculation potential

	Depth averaged temperature increase at the intake [°C]	
	mean	**max**
Case01	<0.1	<0.2
Case02	<0.1	<0.1
Case03	<0.1	<0.2
Case04	<0.1	<0.2
Case05	<0.1	<0.2
Case05b	<0.1	<0.2
Case06	<0.1	<0.1
Case07	<0.1	<0.6
Case08	1.2	4.3
Case09	<0.2	<0.5
Case09b	<0.2	<0.5
Case 10	<0.1	<0.2
Case 11	<0.1	<0.2
Case 12	<0.1	<0.2
Case 13	<0.1	<0.2
Case 14	<0.1	<0.2

B Mean temperature footprints

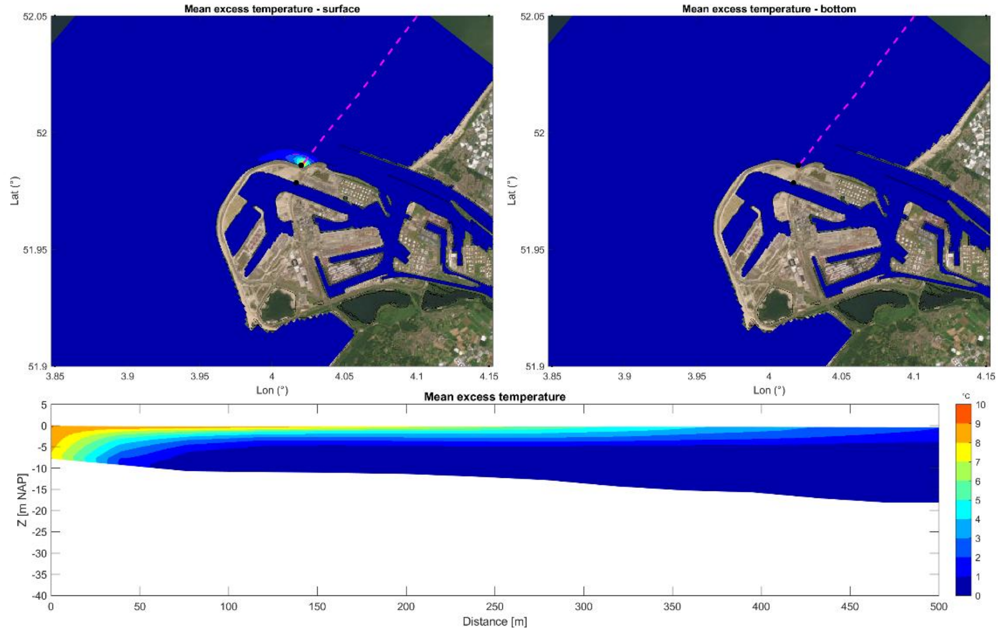

Figure B.1 Mean temperature footprint Case 1, 6000 MWth, configuration 1 – discharge case 2, DT=9 °C (Zoom 1).

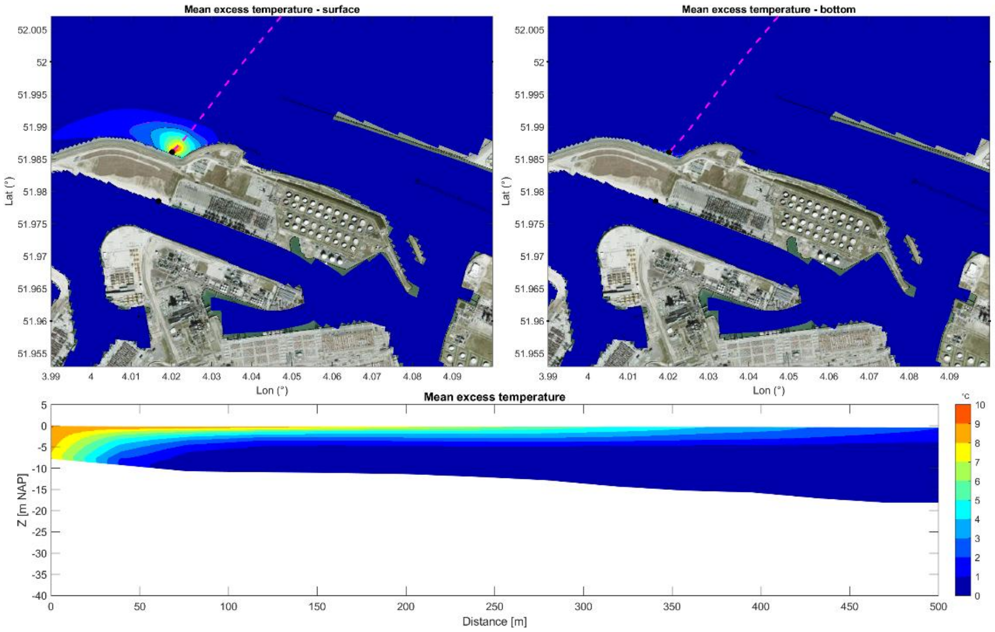

Figure B.2 Mean temperature footprint Case 1, 6000 MWth, configuration 1 – discharge case 2, DT=9 °C (Zoom 2).

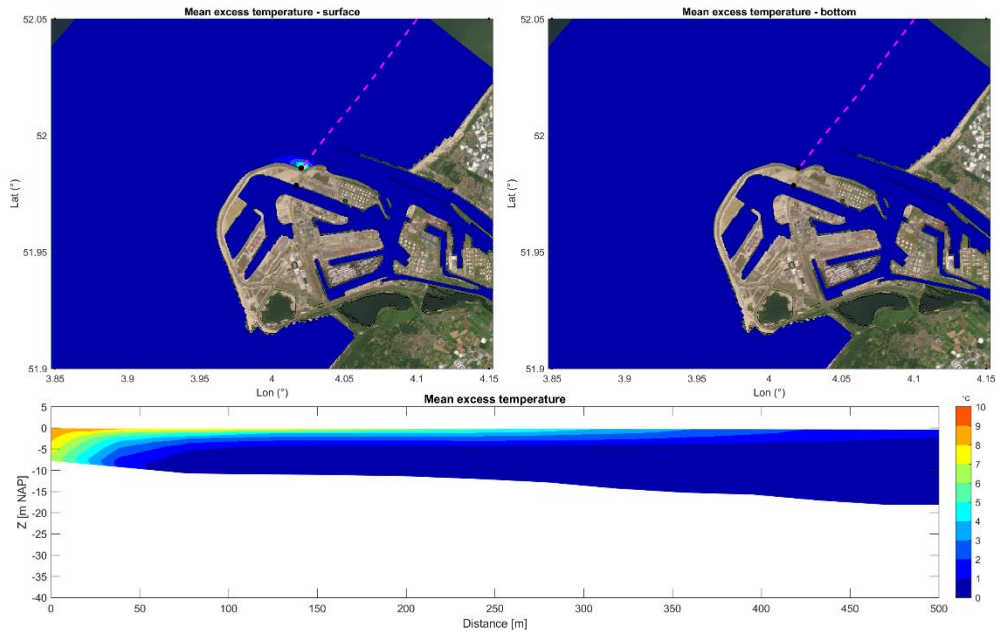

Figure B.3 *Mean temperature footprint Case 2, 4000 MWth, configuration 1 – discharge case 2, DT=9 °C (Zoom 1).*

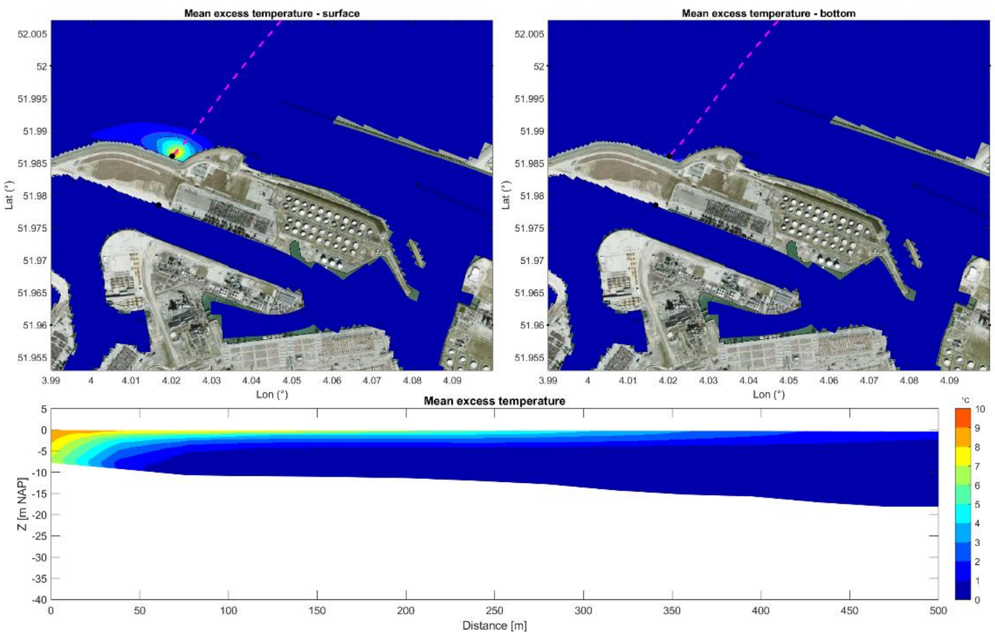

Figure B.4 *Mean temperature footprint Case 2, 4000 MWth, configuration 1 – discharge case 2, DT=9 °C (Zoom 2).*

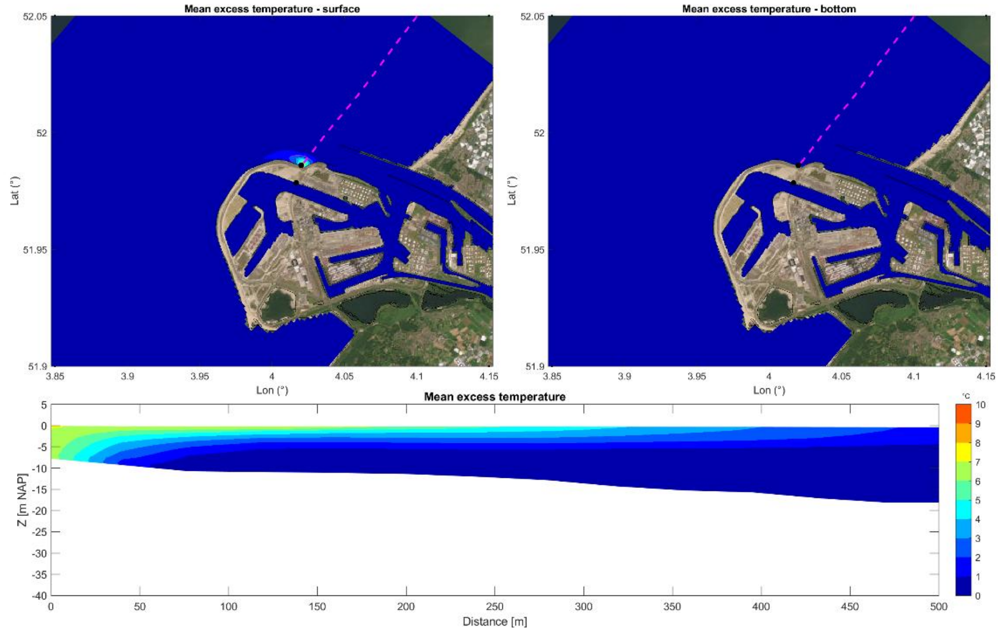

Figure B.5 Mean temperature footprint Case 3, 6000 MWth, configuration 1 – discharge case 1, DT=7 °C (Zoom 1).

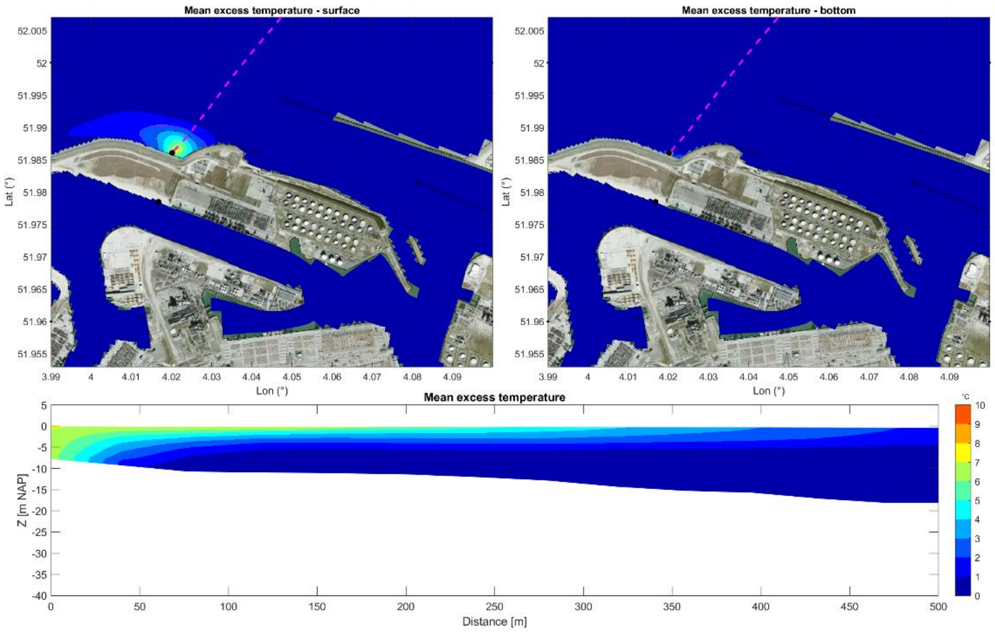

Figure B.6 Mean temperature footprint Case 3, 6000 MWth, configuration 1 – discharge case 1, DT=7 °C (Zoom 2).

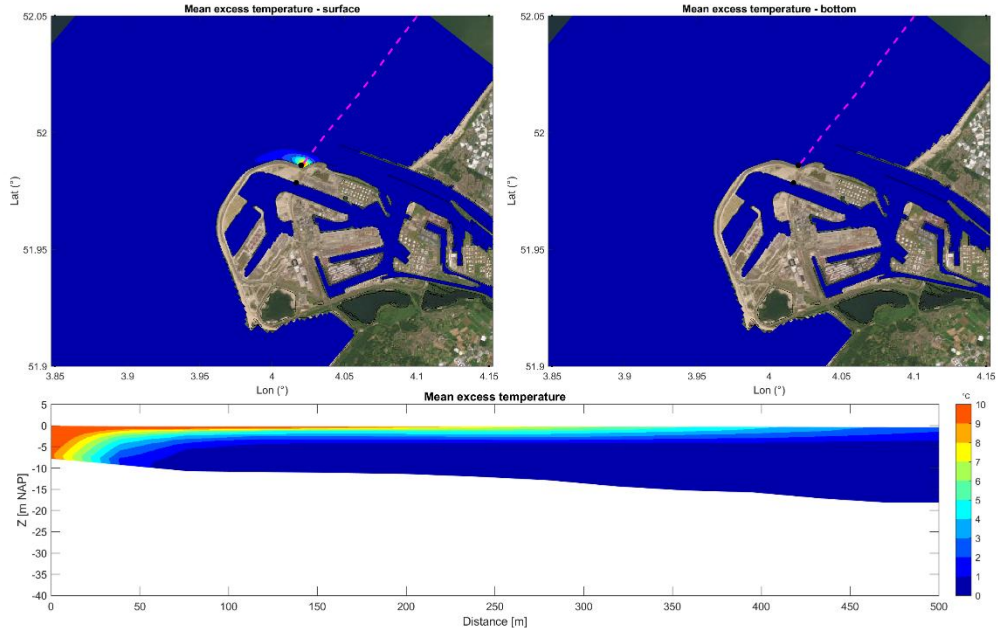

Figure B.7 Mean temperature footprint Case 4, 6000 MWth, configuration 1 – discharge case 3, DT=12 °C (Zoom 1).

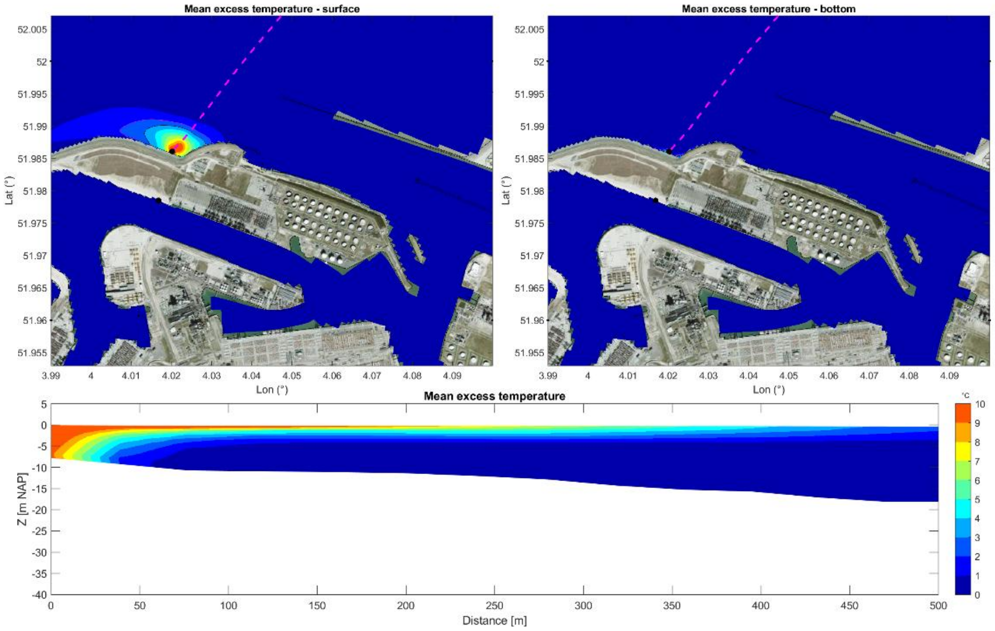

Figure B.8 Mean temperature footprint Case 4, 6000 MWth, configuration 1 – discharge case 3, DT=12 °C (Zoom 2).

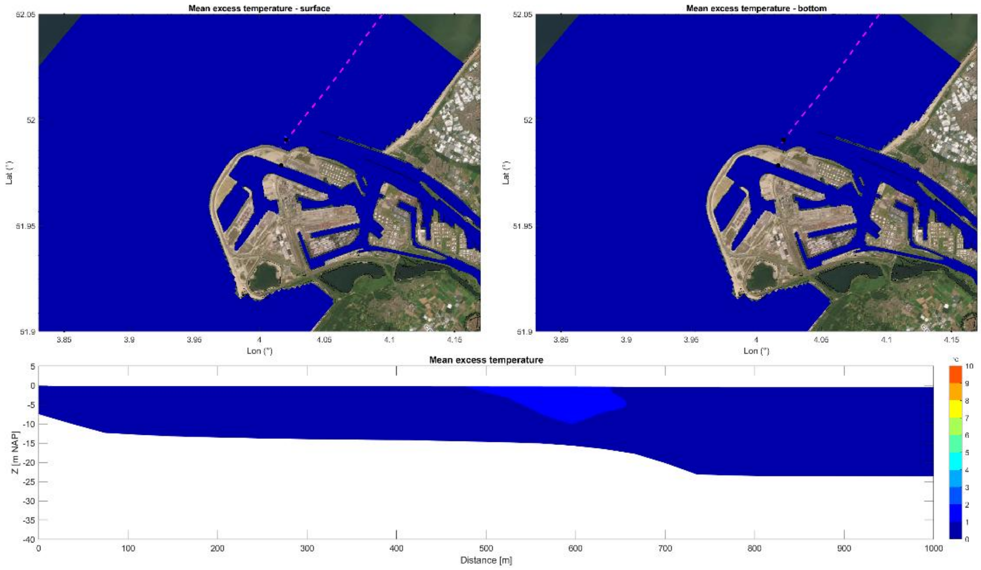

Figure B.9 Mean temperature footprint Case 5, 6000 MWth, configuration 2 – discharge case 2, DT=9 °C (Zoom 1).

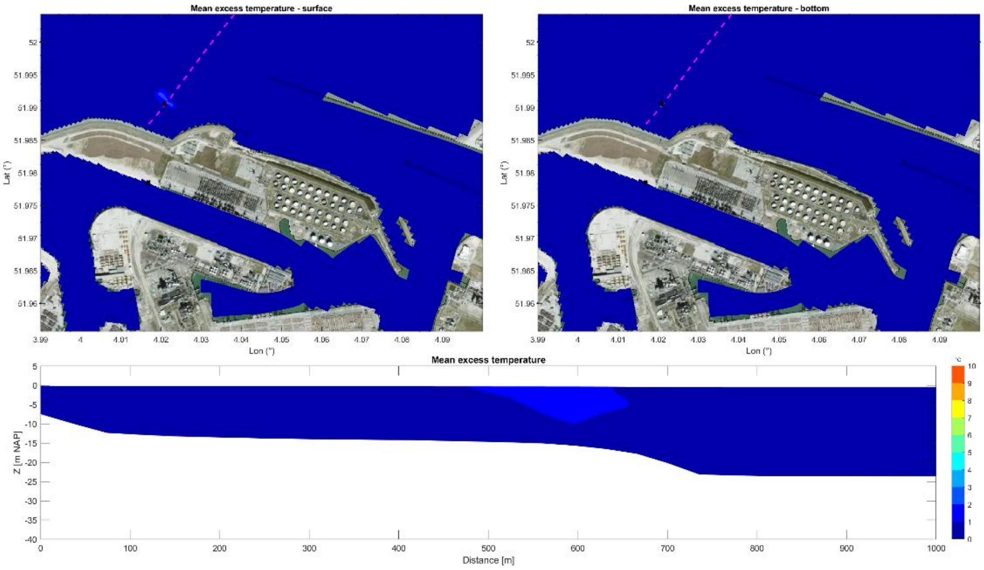

Figure B.10 Mean temperature footprint Case 5, 6000 MWth, configuration 2 – discharge case 2, DT=9 °C (Zoom 2).

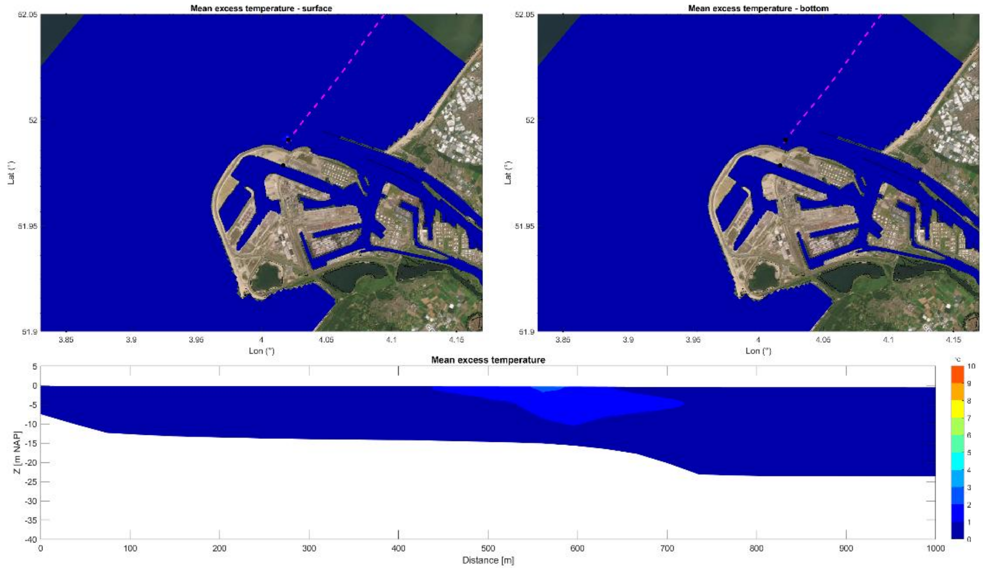

Figure B.11 Mean temperature footprint Case 5b, 6000 MWth, configuration 2 – discharge case 3, DT=12 °C (Zoom 1).

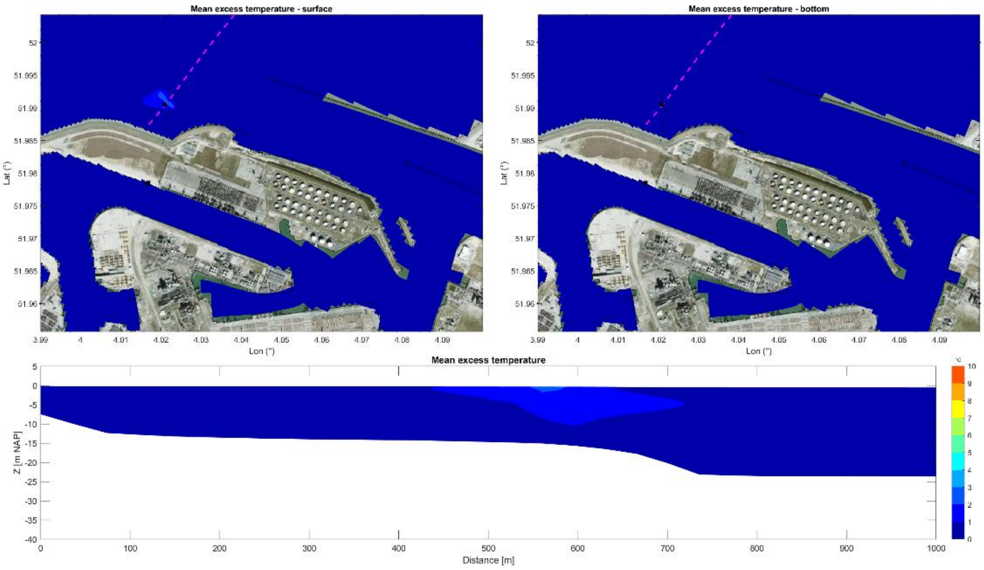

Figure B.12 Mean temperature footprint Case 5b, 6000 MWth, configuration 2 – discharge case 3, DT=12 °C (Zoom 2).

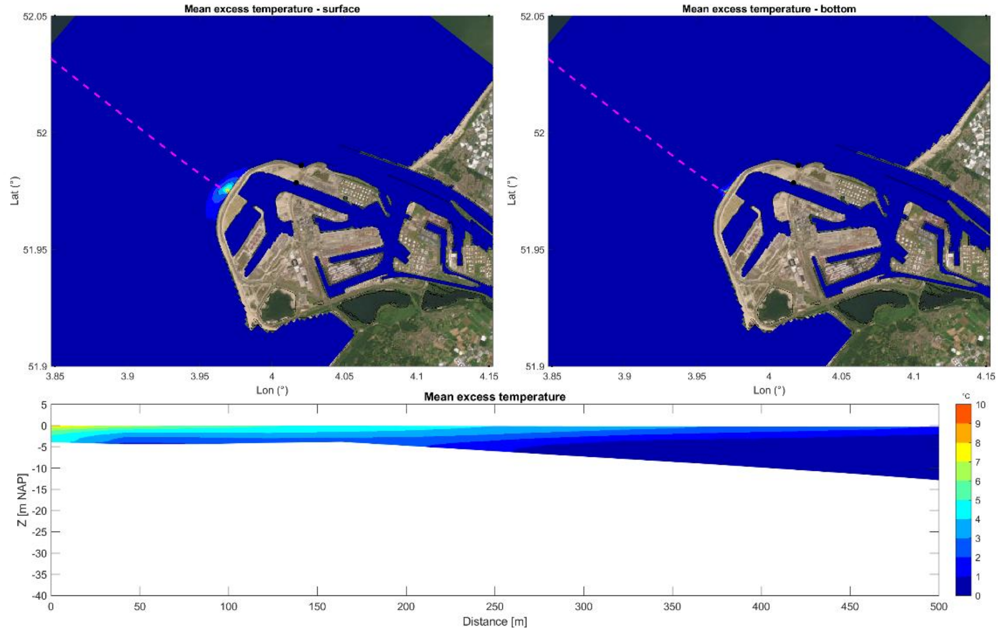

Figure B.13 Mean temperature footprint Case 6, 6000 MWth, configuration 3 – discharge case 2, DT=9 °C (Zoom 1).

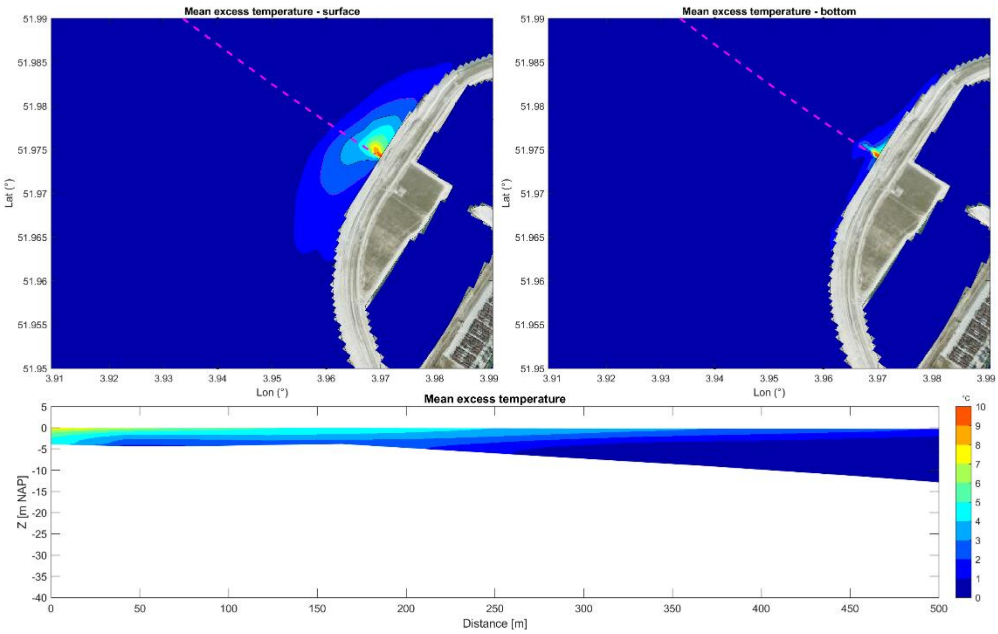

Figure B.14 Mean temperature footprint Case 6, 6000 MWth, configuration 3 – discharge case 2, DT=9 °C (Zoom 2).

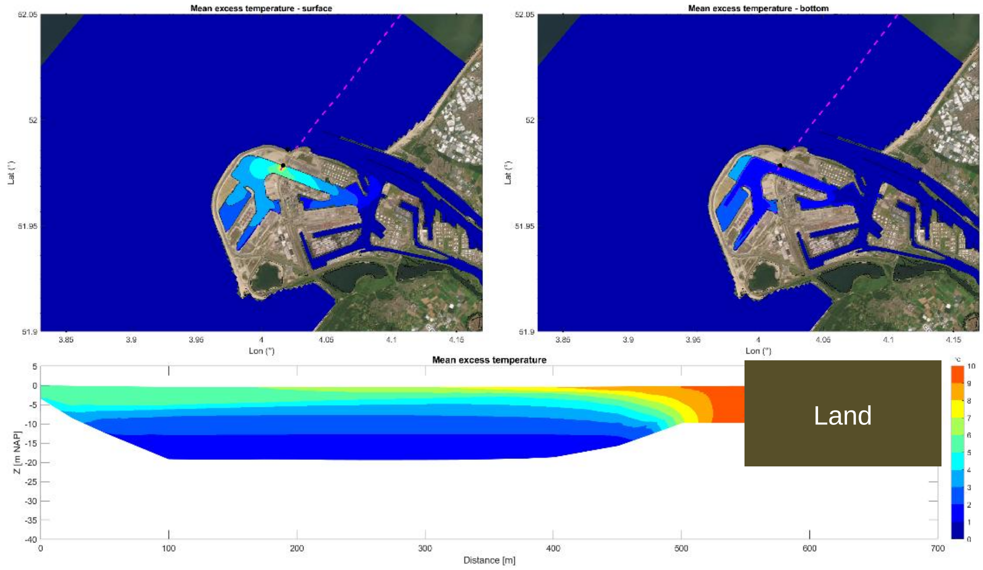

Figure B.15 Mean temperature footprint Case 7, 6000 MWth, configuration 4 – discharge case 2, DT=9 °C (Zoom 1).

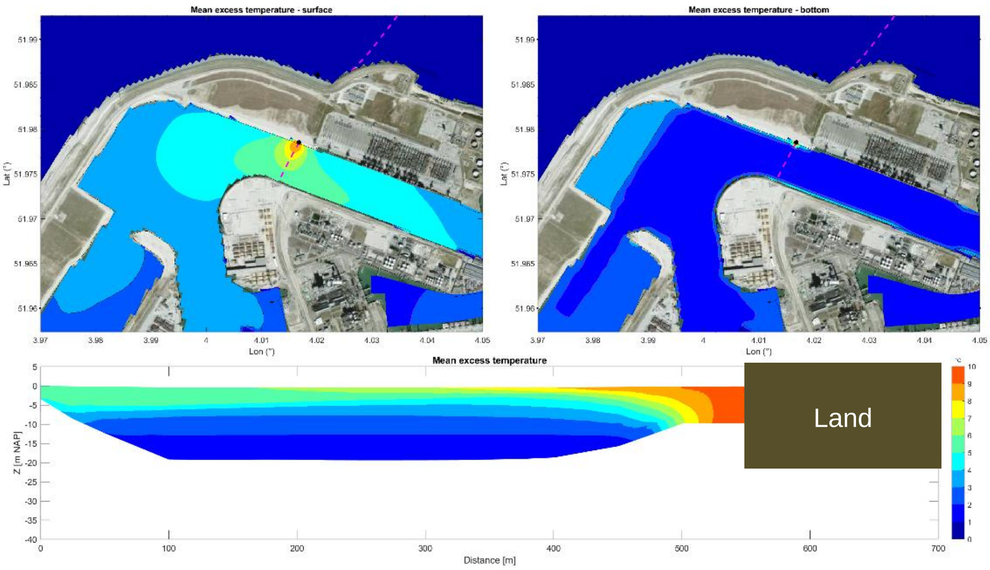

Figure B.16 Mean temperature footprint Case 7, 6000 MWth, configuration 4 – discharge case 2, DT=9 °C (Zoom 1).

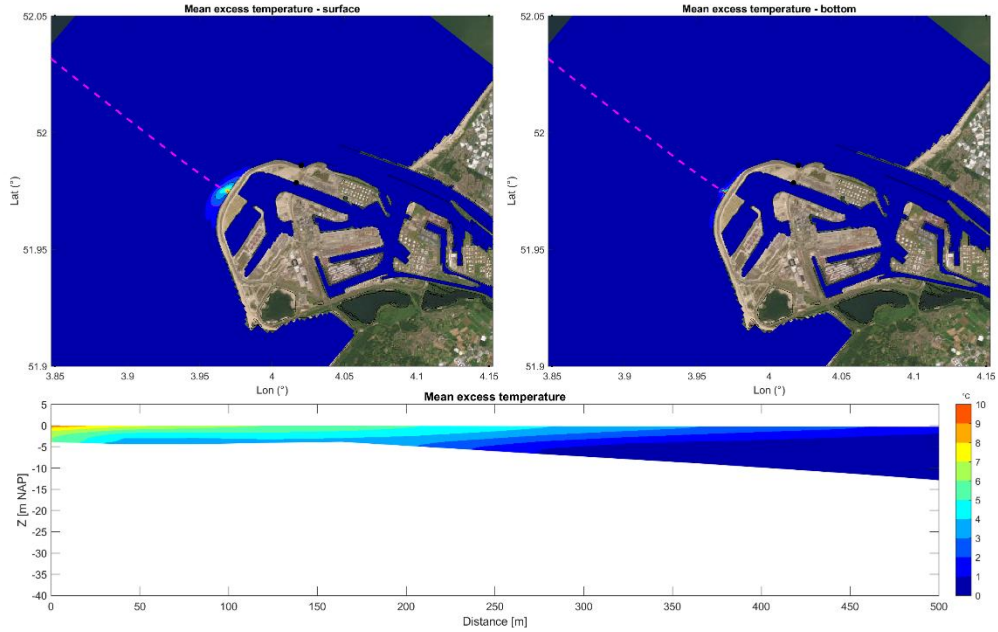

Figure B.17 Mean temperature footprint Case 8, 6000 MWth, configuration 5 – discharge case 2, DT=9 °C (Zoom 1).

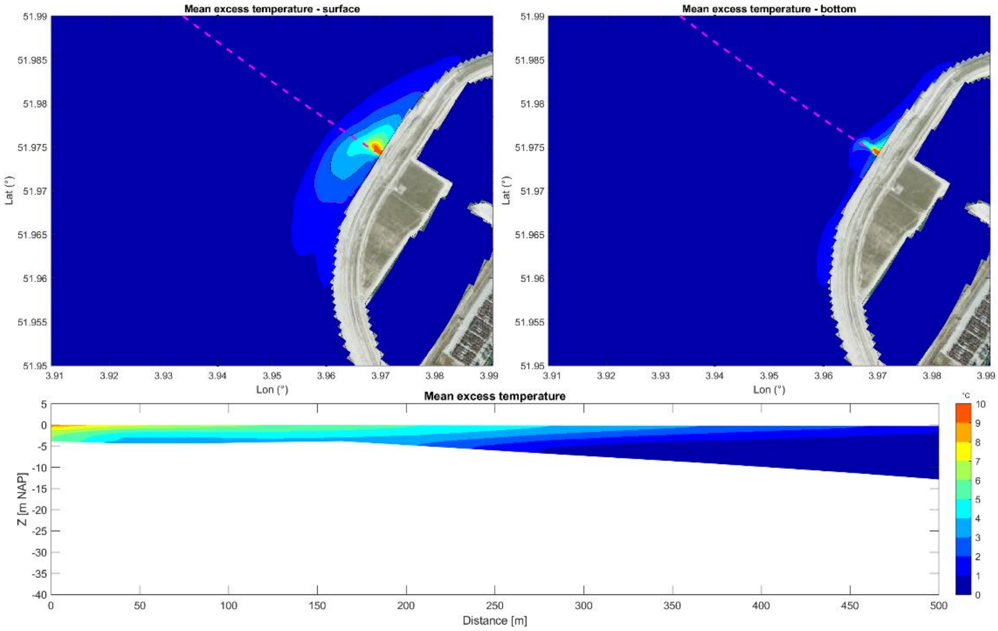

Figure B.18 Mean temperature footprint Case 8, 6000 MWth, configuration 5 – discharge case 2, DT=9 °C (Zoom 2).

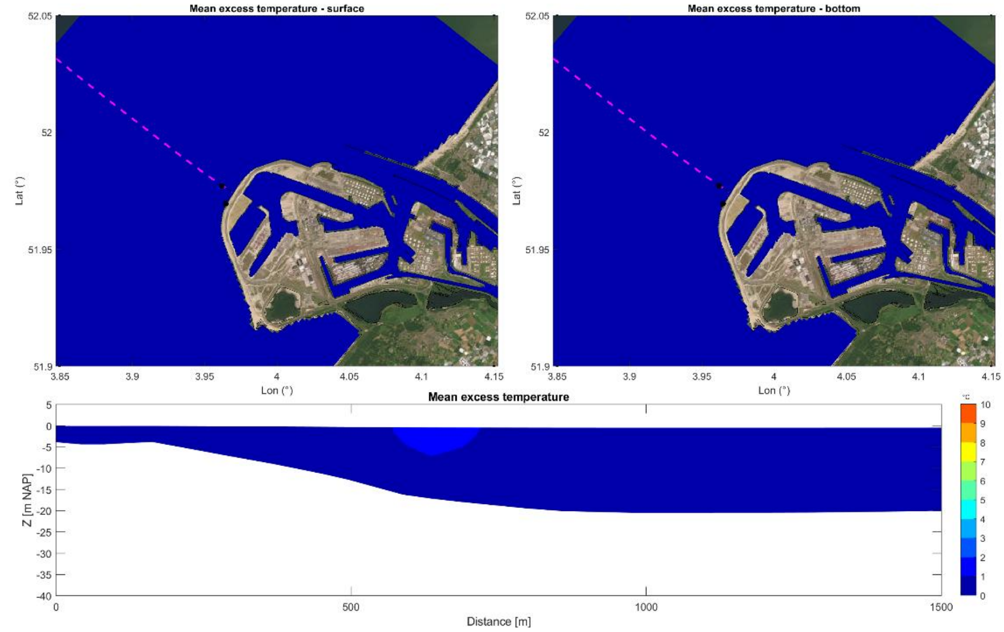

Figure B.19 Mean temperature footprint Case 9, 6000 MWth, configuration 6 – discharge case 2, DT=9 °C (Zoom 1).

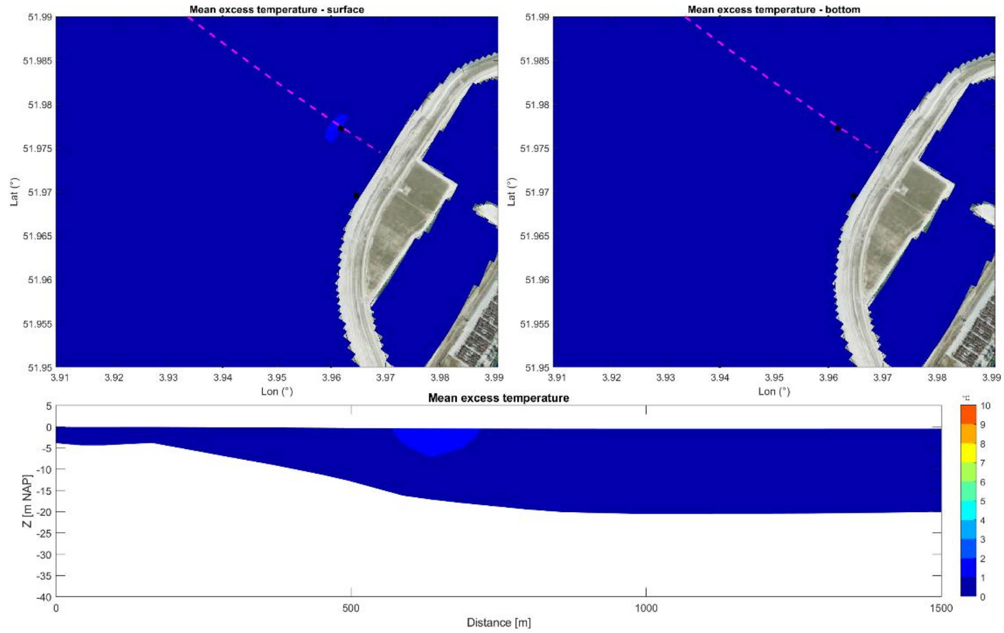

Figure B.20 Mean temperature footprint Case 9, 6000 MWth, configuration 6 – discharge case 2, DT=9 °C (Zoom 2).

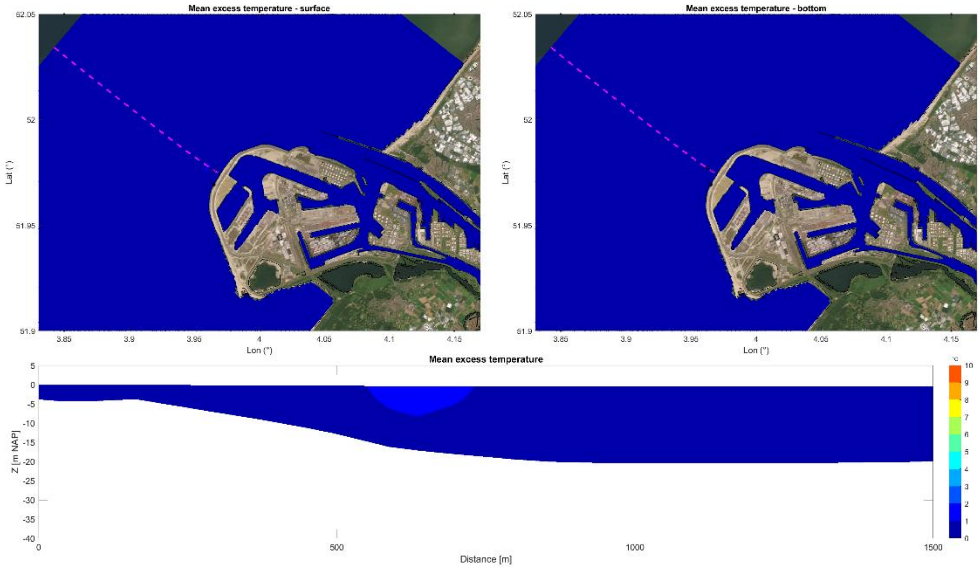

Figure B.21 Mean temperature footprint Case 9b, 6000 MWth, configuration 6 – discharge case 3, DT=12 °C (Zoom 1).

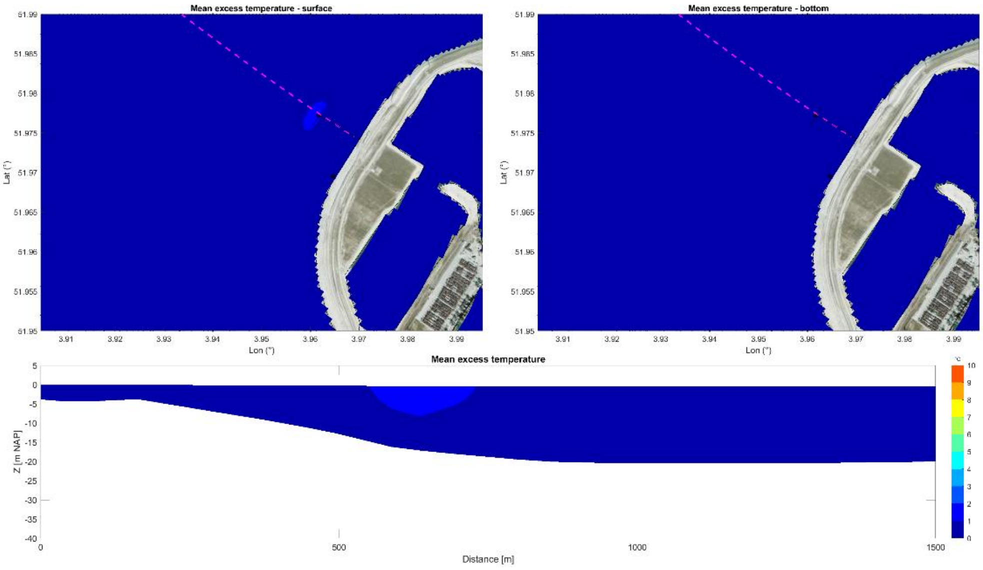

Figure B.22 Mean temperature footprint Case 9b, 6000 MWth, configuration 6 – discharge case 3, DT=12 °C (Zoom 1).

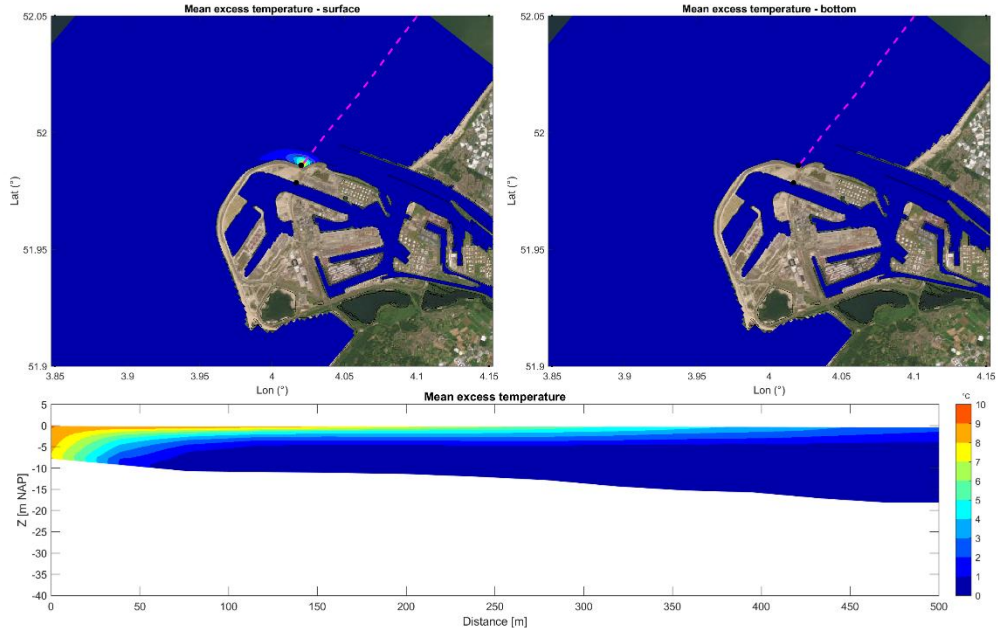

Figure B.23 Mean temperature footprint Case 10, 6000 MWth, configuration 1 – discharge case 2, DT=9 °C, modified stratification at the model boundaries (Zoom 1).

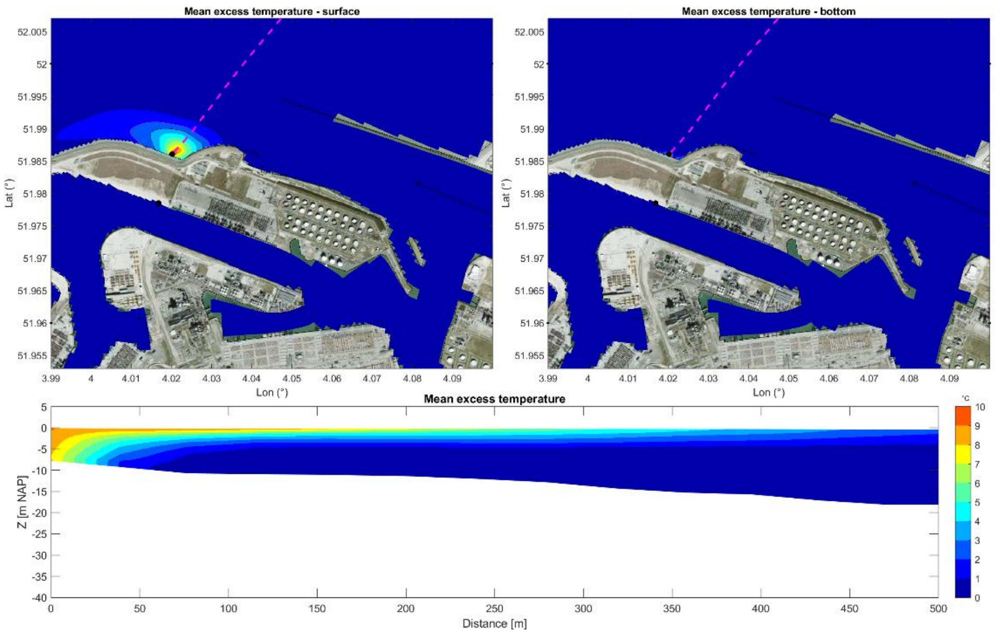

Figure B.24 Mean temperature footprint Case 10, 6000 MWth, configuration 1 – discharge case 2, DT=9 °C, modified stratification at the model boundaries (Zoom 2).

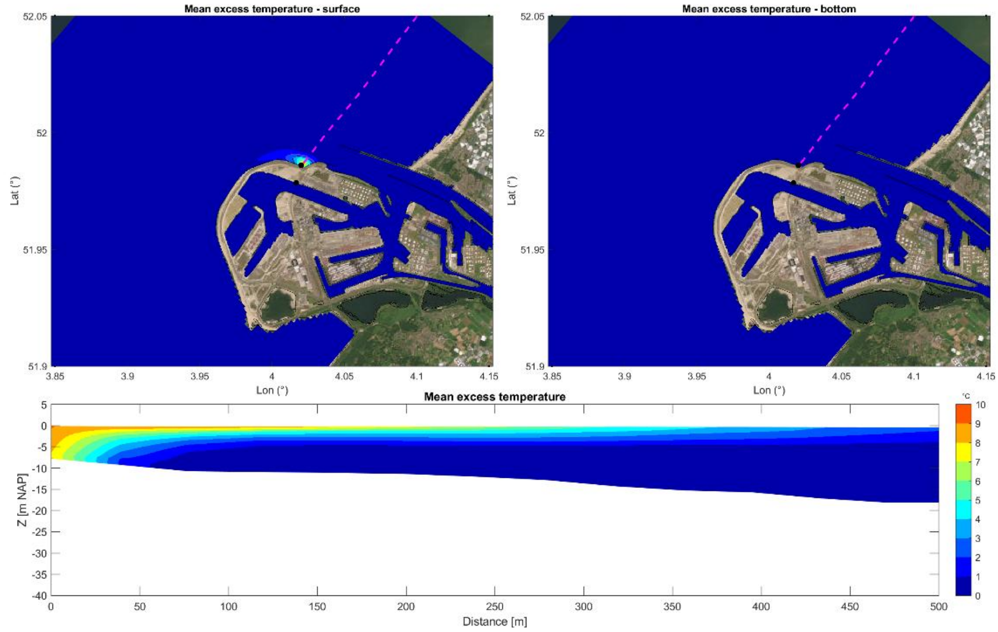

Figure B.25 Mean temperature footprint Case 11, 6000 MWth, configuration 1 – discharge case 2, DT=9 °C, uniform fresh water at the eastern model boundary (Zoom 1).

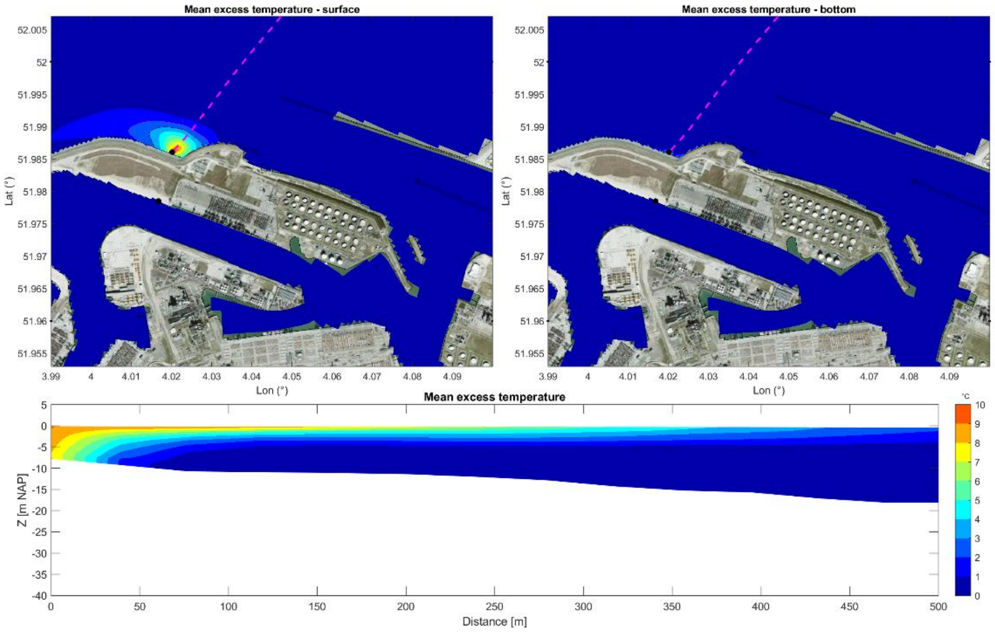

Figure B.26 Mean temperature footprint Case 11, 6000 MWth, configuration 1 – discharge case 2, DT=9 °C, uniform fresh water at the eastern model boundary (Zoom 2).

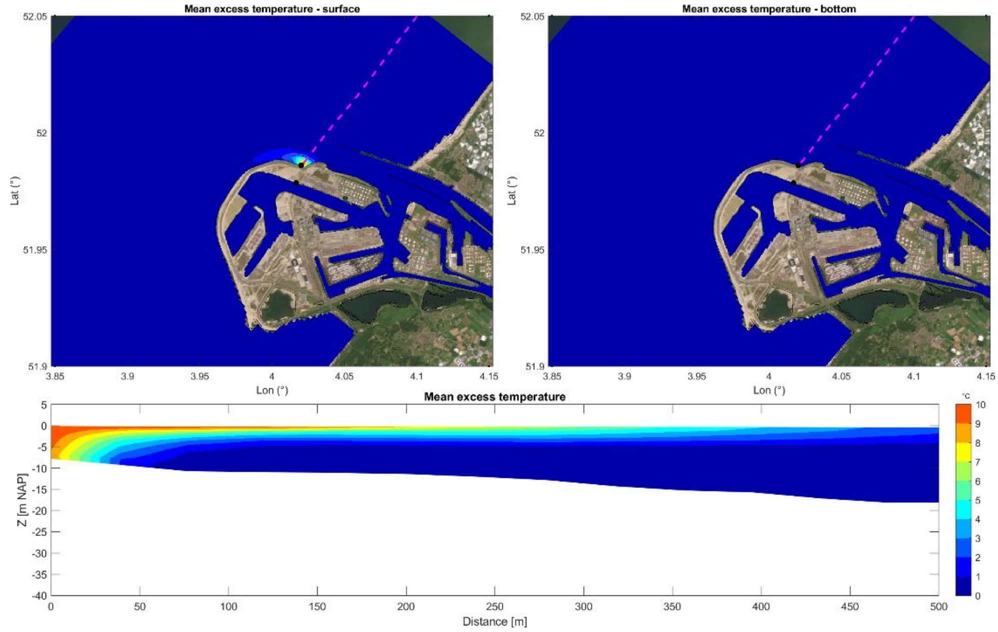

Figure B.27 Mean temperature footprint Case 12, 6000 MWth, configuration 1 – discharge case 2, DT=10 °C (Zoom 1).

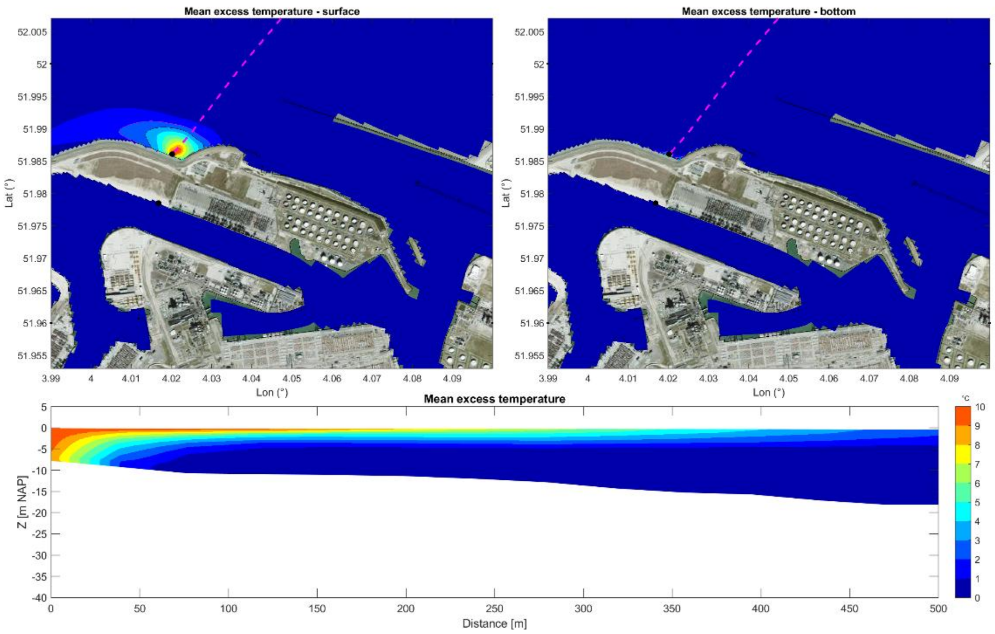

Figure B.28 Mean temperature footprint Case 12, 6000 MWth, configuration 1 – discharge case 2, DT=10 °C (Zoom 2).

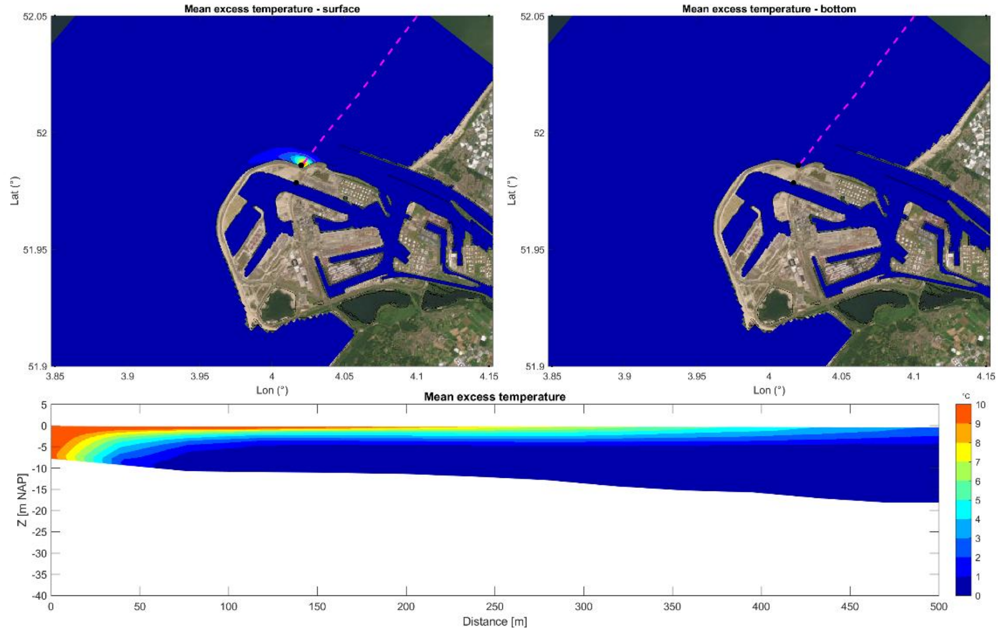

Figure B.29 Mean temperature footprint Case 13, 6000 MWth, configuration 1 – discharge case 2, DT=11 °C (Zoom 1).

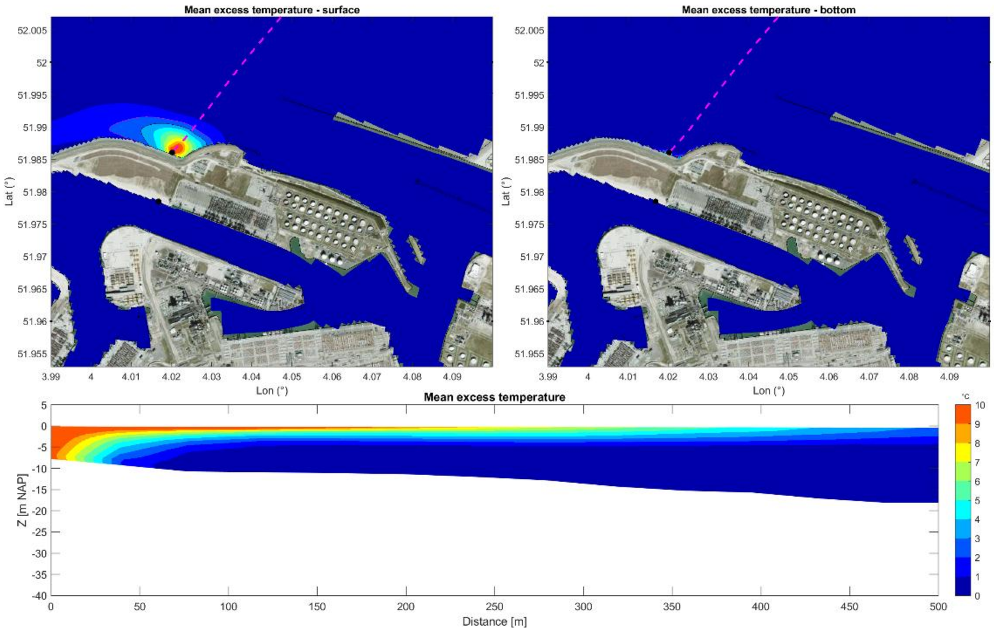

Figure B.30 Mean temperature footprint Case 13, 6000 MWth, configuration 1 – discharge case 2, DT=11 °C (Zoom 2).

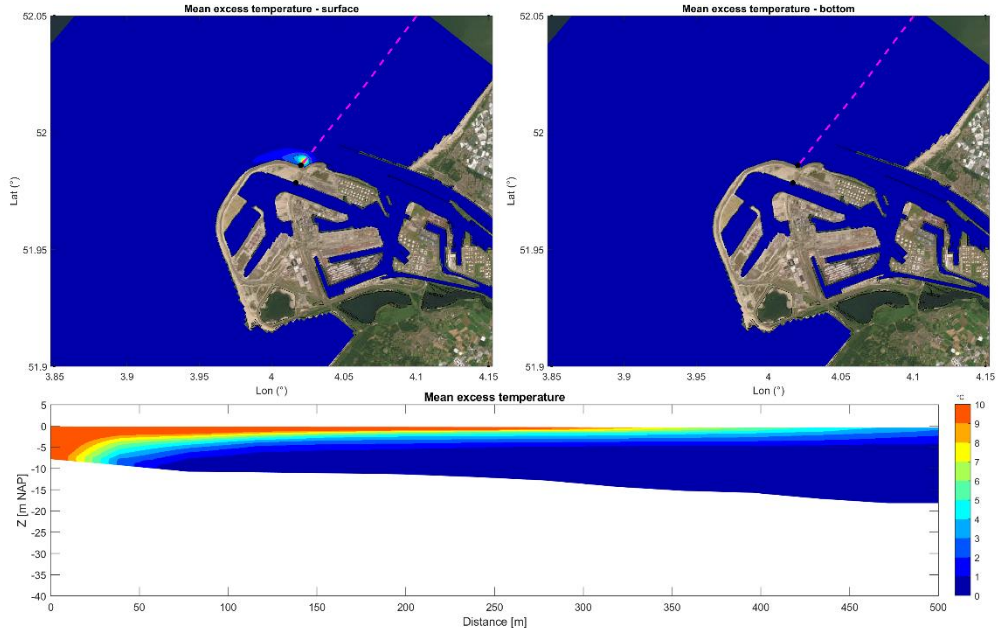

Figure B.31 Mean temperature footprint Case 14, 6000 MWth, configuration 1 – discharge case 3, DT=12 °C, including breakwaters (Zoom 1).

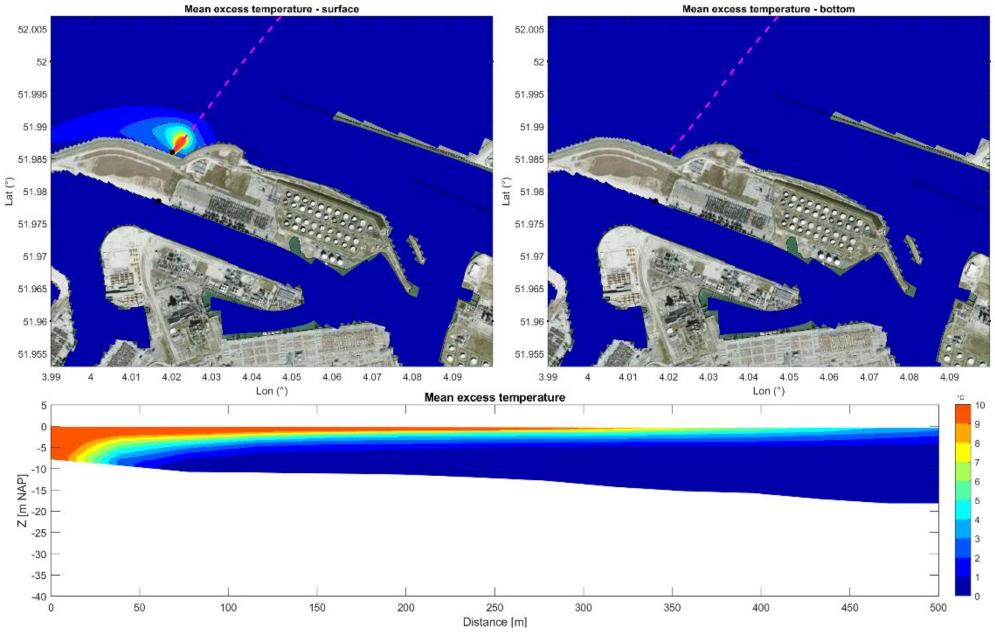

Figure B.32 Mean temperature footprint Case 14, 6000 MWth, configuration 1 – discharge case 3, DT=12 °C, including breakwaters (Zoom 2).

C Maximum temperature footprints

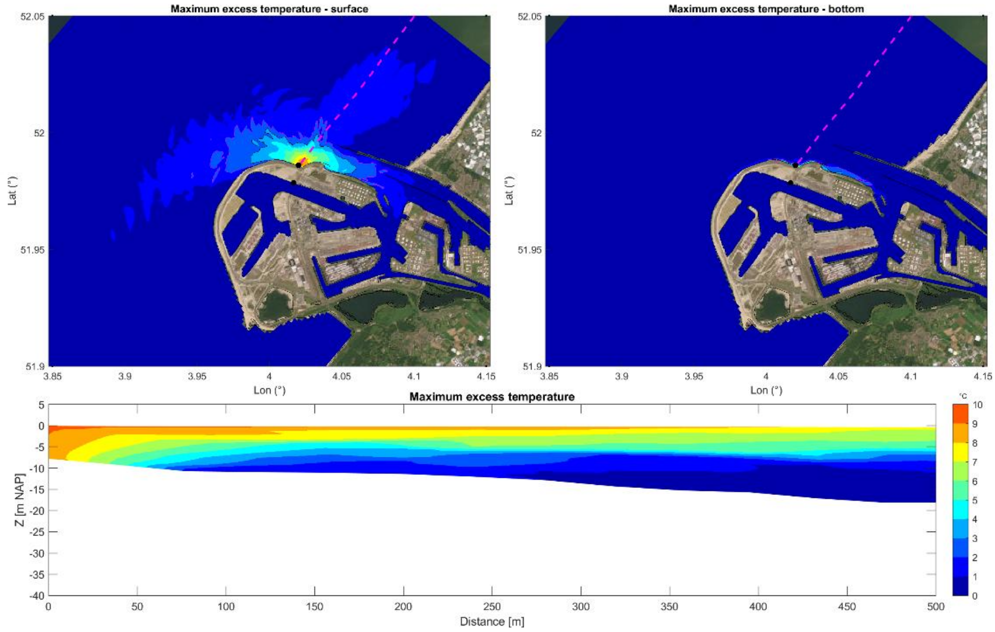

Figure C.1 Max temperature footprint Case 1, 6000 MWth, configuration 1 – discharge case 2, DT=9 °C (Zoom 1).

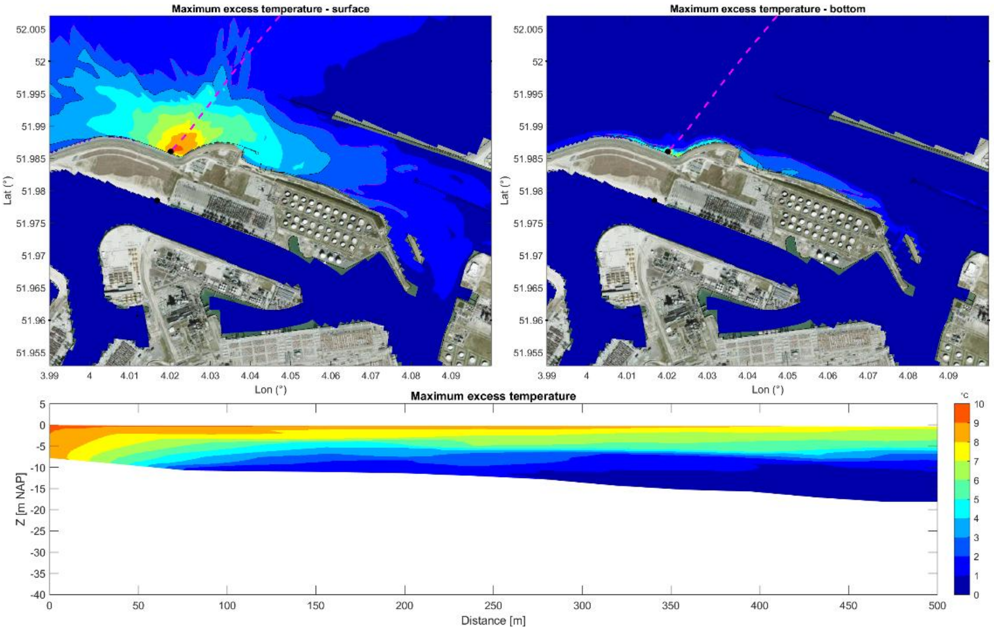

Figure C.2 Max temperature footprint Case 1, 6000 MWth, configuration 1 – discharge case 2, DT=9 °C (Zoom 2).

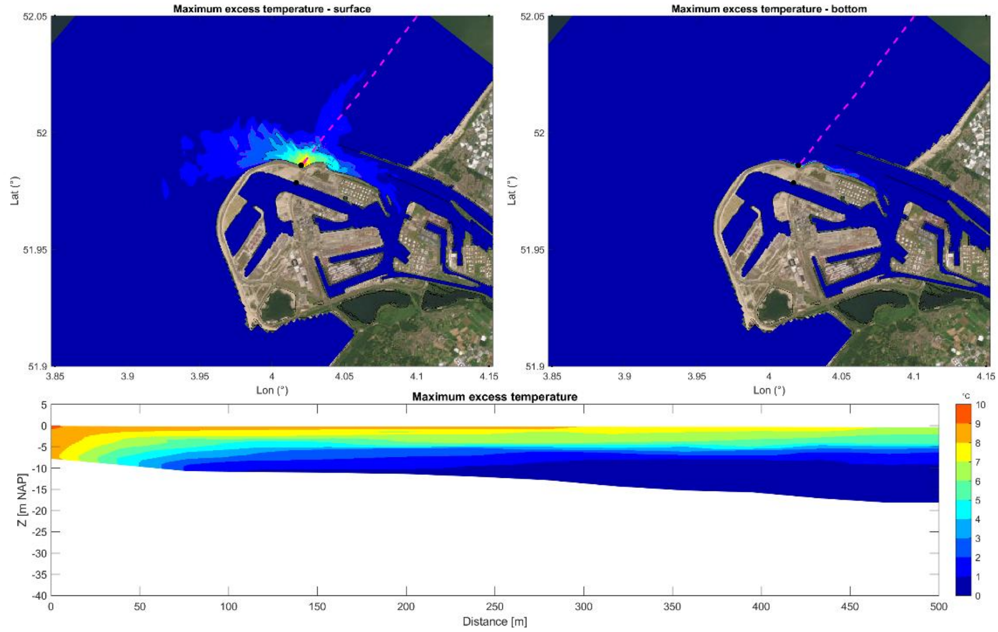

Figure C.3 Max temperature footprint Case 2, 4000 MWth, configuration 1 – discharge case 2, DT=9 °C (Zoom 1).

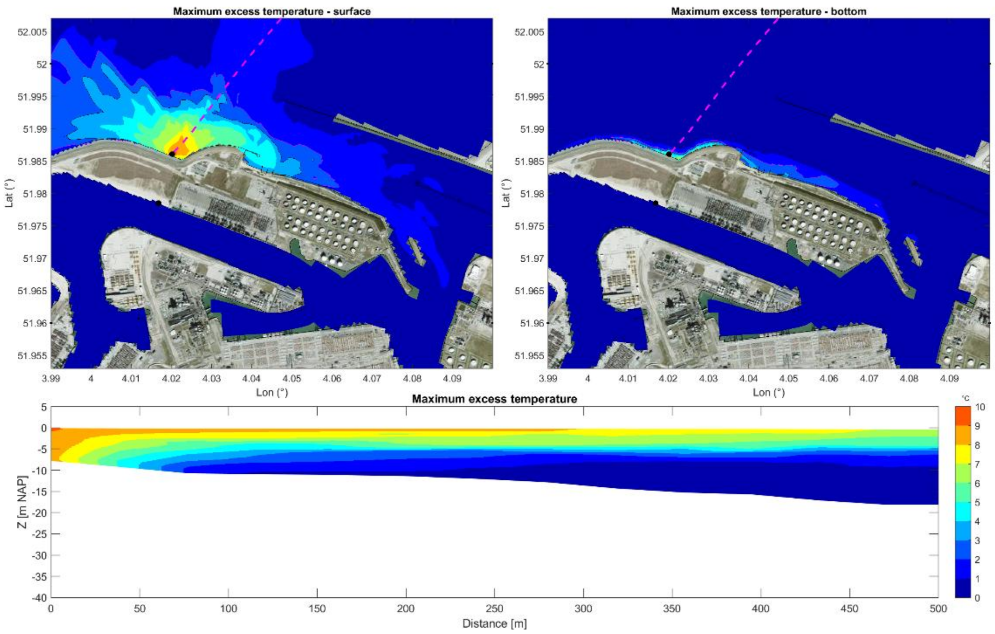

Figure C.4 Max temperature footprint Case 2, 4000 MWth, configuration 1 – discharge case 2, DT=9 °C (Zoom 2).

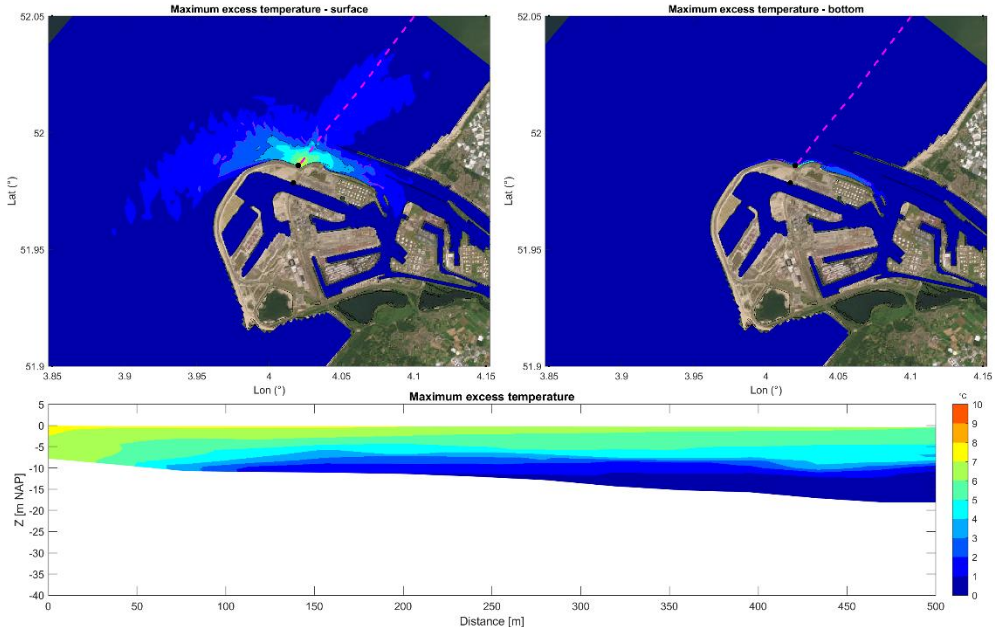

Figure C.5 Max temperature footprint Case 3, 6000 MWth, configuration 1 – discharge case 1, DT=7 °C (Zoom 1).

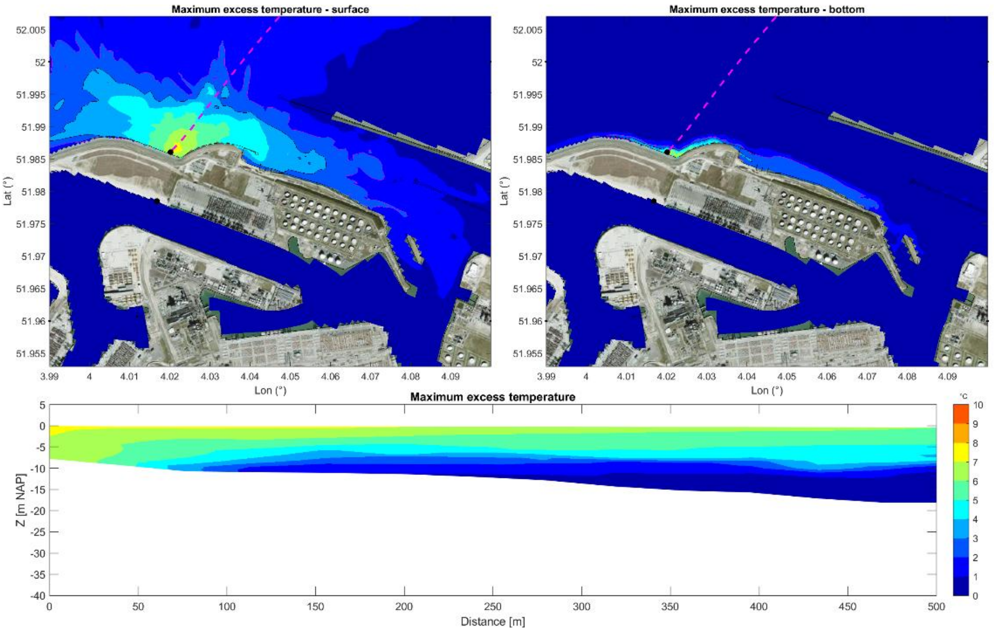

Figure C.6 Max temperature footprint Case 3, 6000 MWth, configuration 1 – discharge case 1, DT=7 °C (Zoom 2).

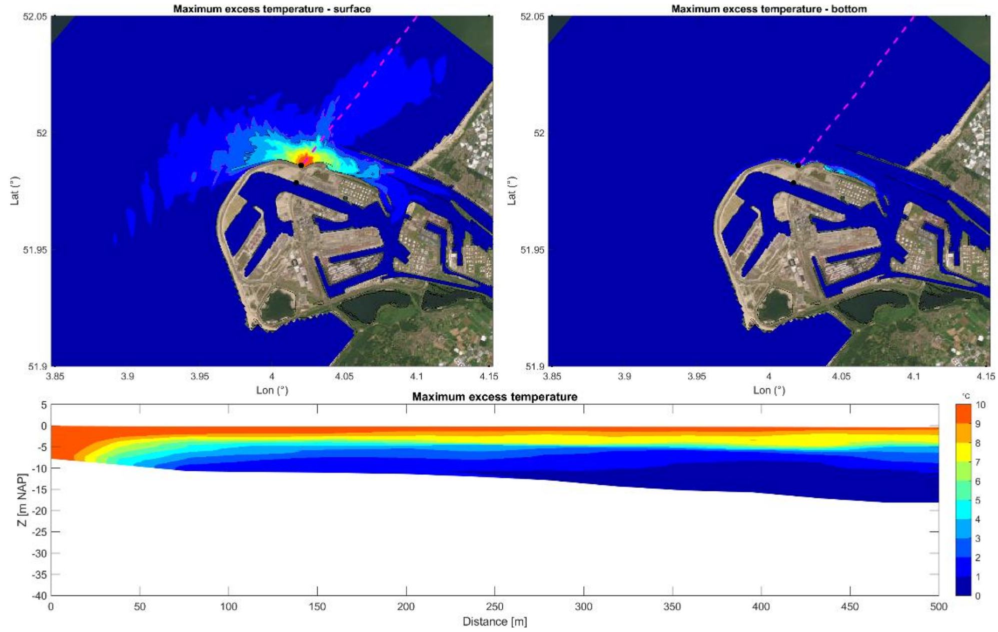

Figure C.7 *Max temperature footprint Case 4, 6000 MWth, configuration 1 – discharge case 3, DT=12 °C (Zoom 1).*

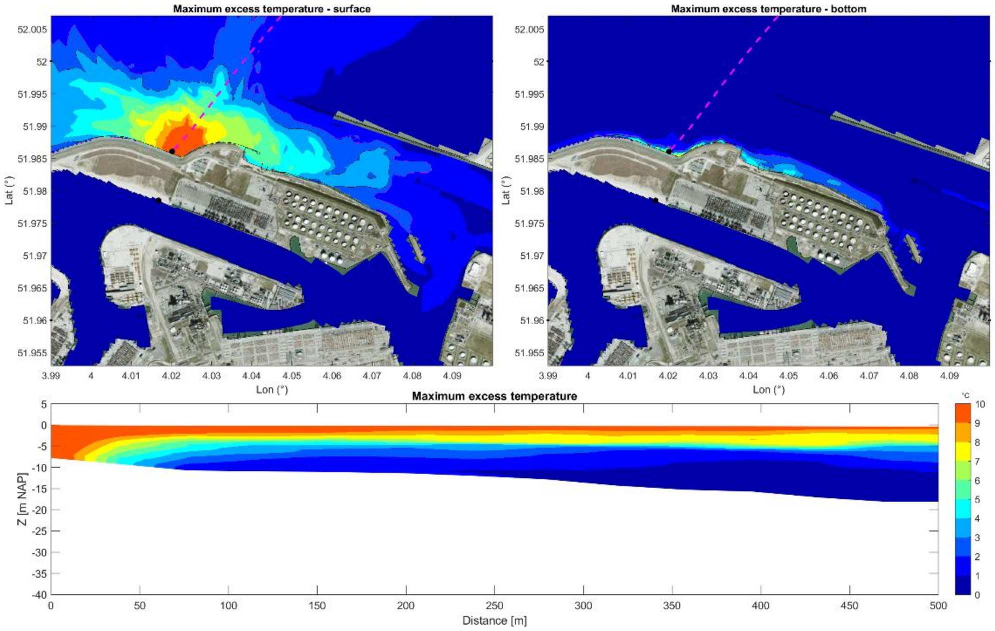

Figure C.8 *Max temperature footprint Case 4, 6000 MWth, configuration 1 – discharge case 3, DT=12 °C (Zoom 2).*

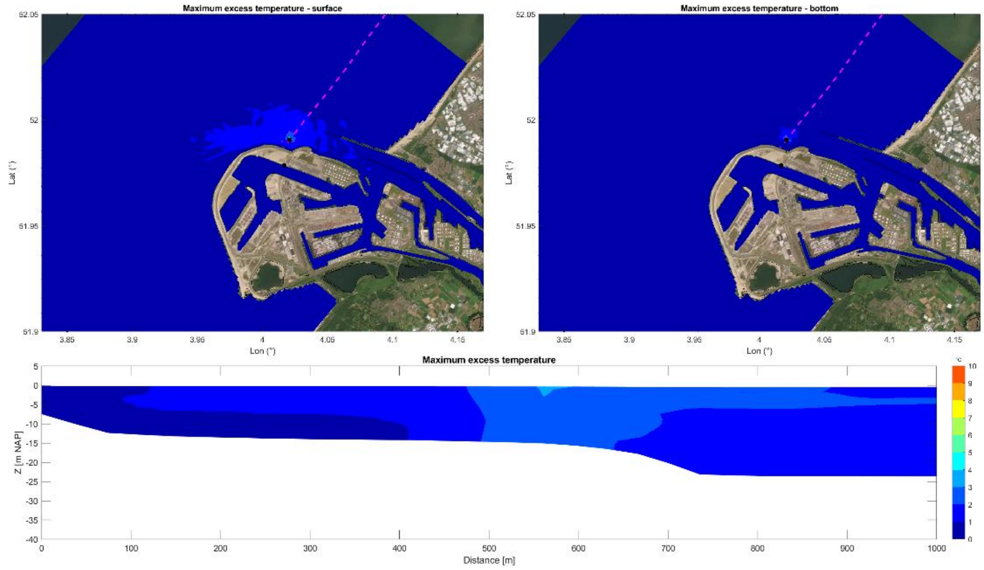

Figure C.9 Max temperature footprint Case 5, 6000 MWth, configuration 2 – discharge case 2, DT=9 °C (Zoom 1).

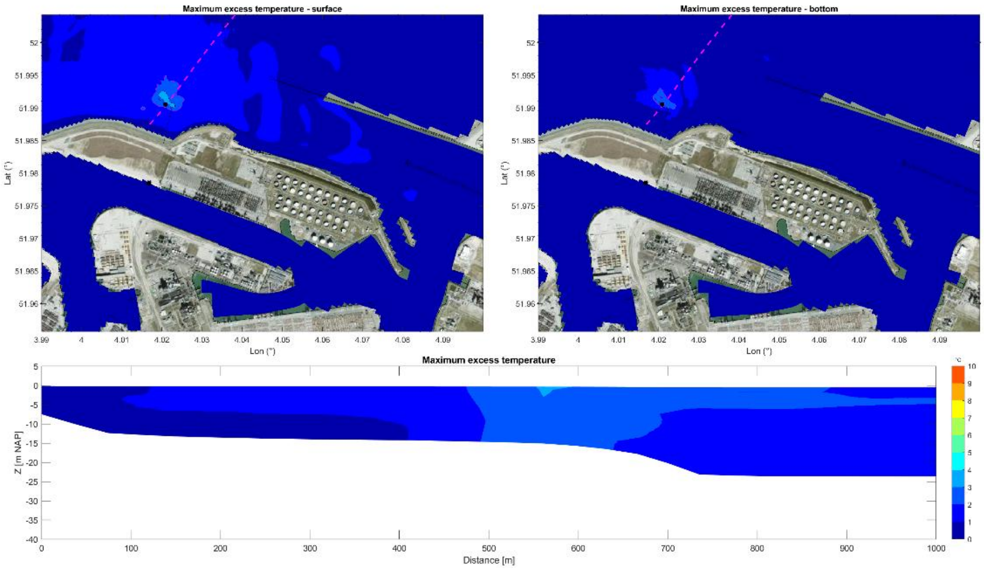

Figure C.10 Max temperature footprint Case 5, 6000 MWth, configuration 2 – discharge case 2, DT=9 °C (Zoom 2).

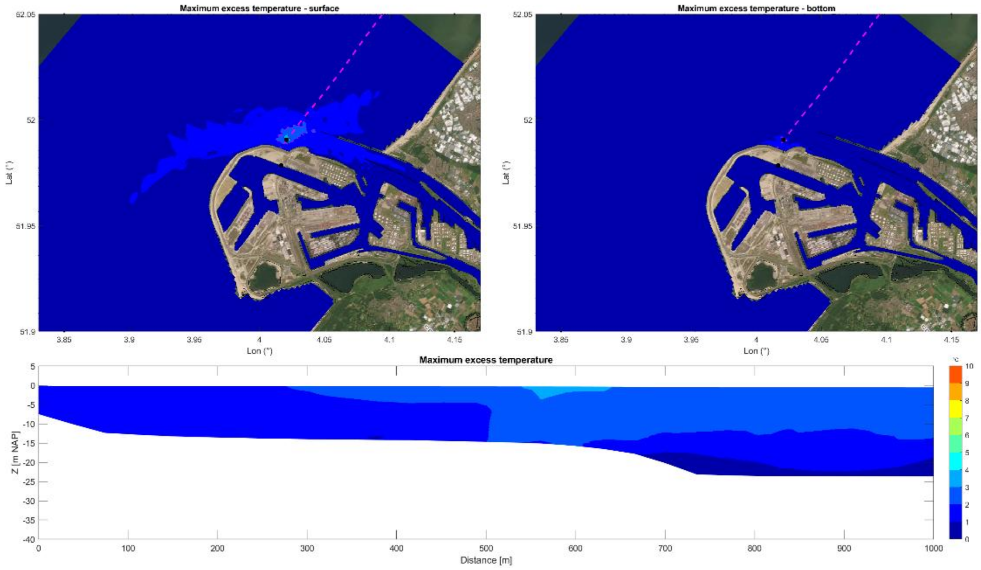

Figure C.11 Max temperature footprint Case 5b, 6000 MWth, configuration 2 – discharge case 3, DT=12 °C (Zoom 1).

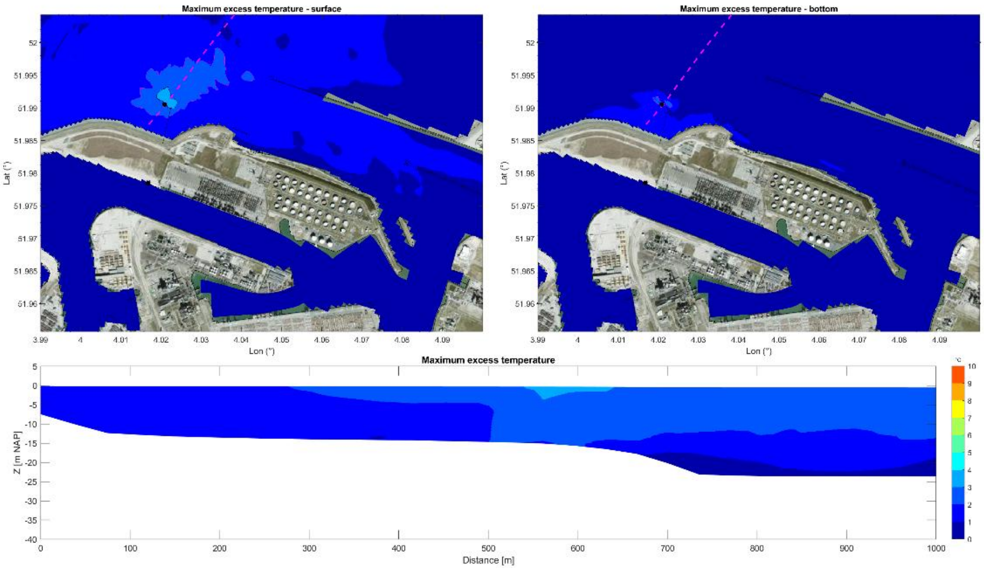

Figure C.12 Max temperature footprint Case 5b, 6000 MWth, configuration 2 – discharge case 3, DT=12 °C (Zoom 2).

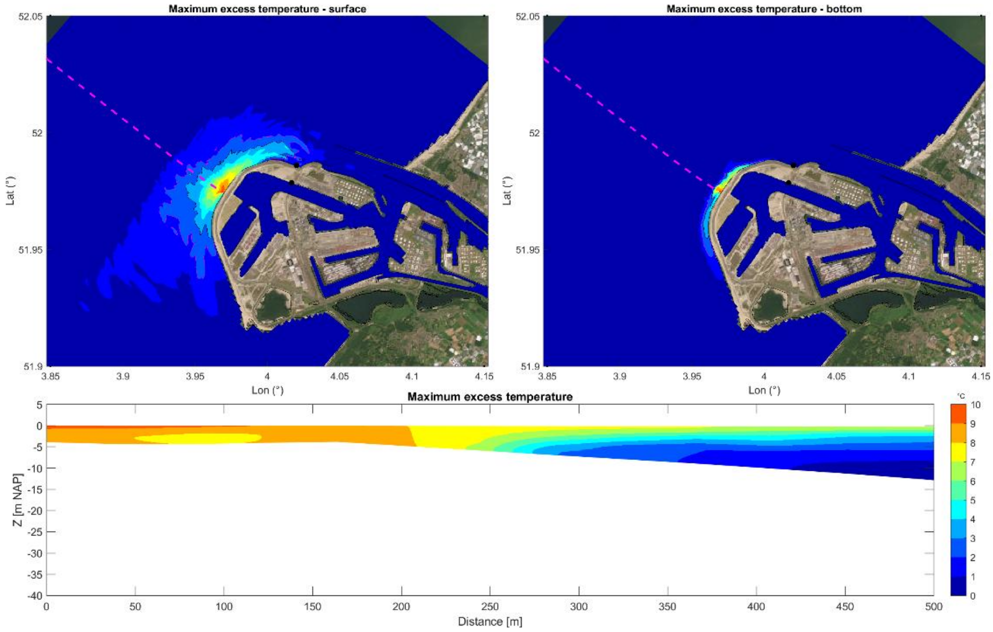

Figure C.13 Max temperature footprint Case 6, 6000 MWth, configuration 3 – discharge case 2, DT=9 °C (Zoom 1).

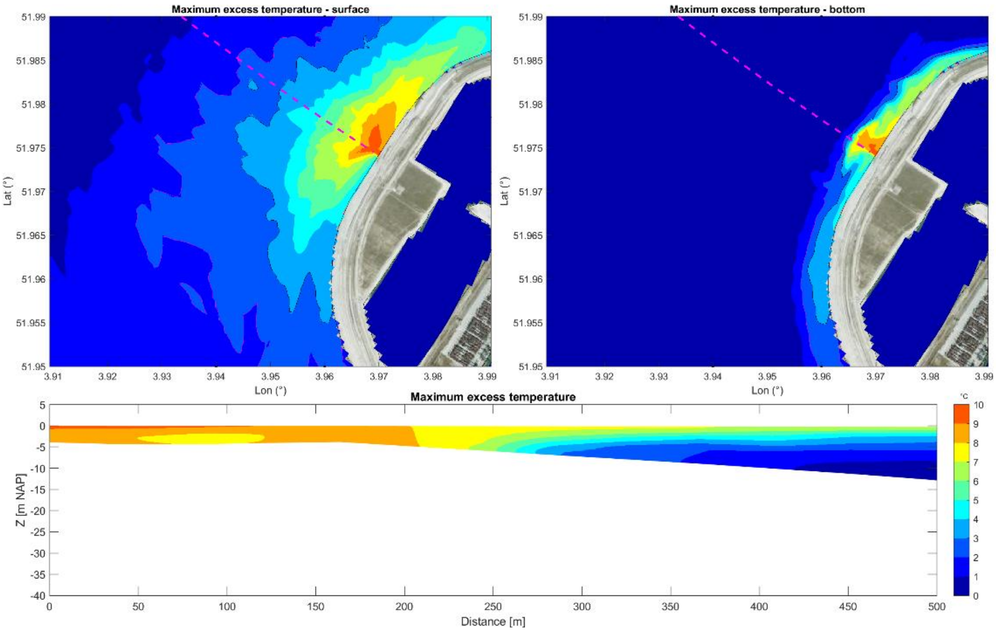

Figure C.14 Max temperature footprint Case 6, 6000 MWth, configuration 3 – discharge case 2, DT=9 °C (Zoom 2).

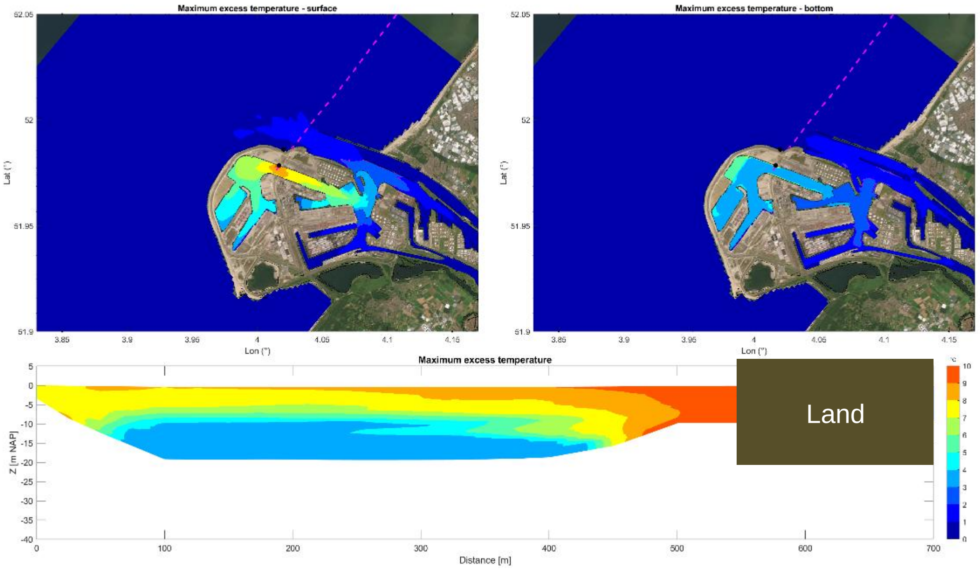

Figure C 15 Max temperature footprint Case 7, 6000 MWth, configuration 4 – discharge case 2, DT=9 °C (Zoom 1).

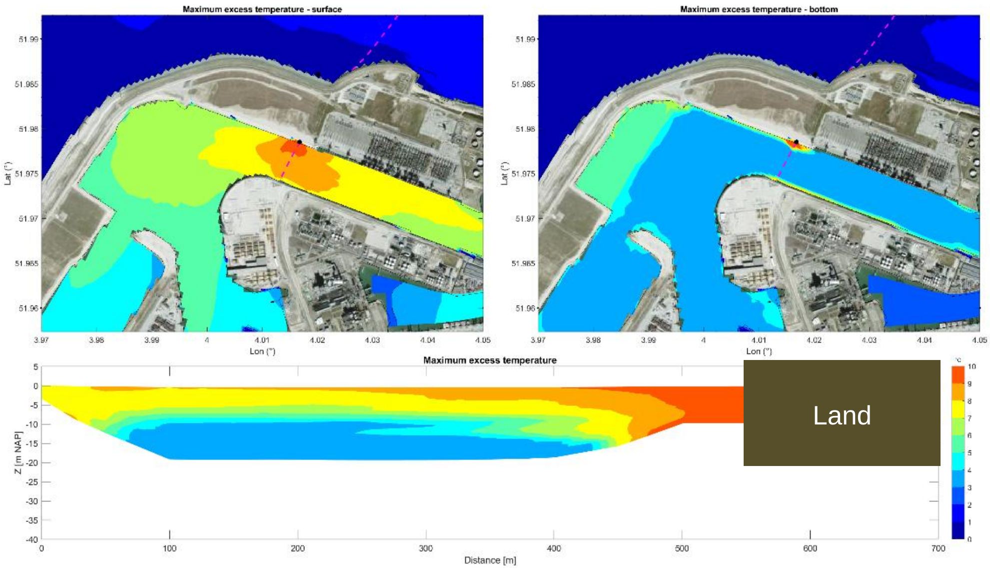

Figure C.16 Max temperature footprint Case 7, 6000 MWth, configuration 4 – discharge case 2, DT=9 °C (Zoom 2).

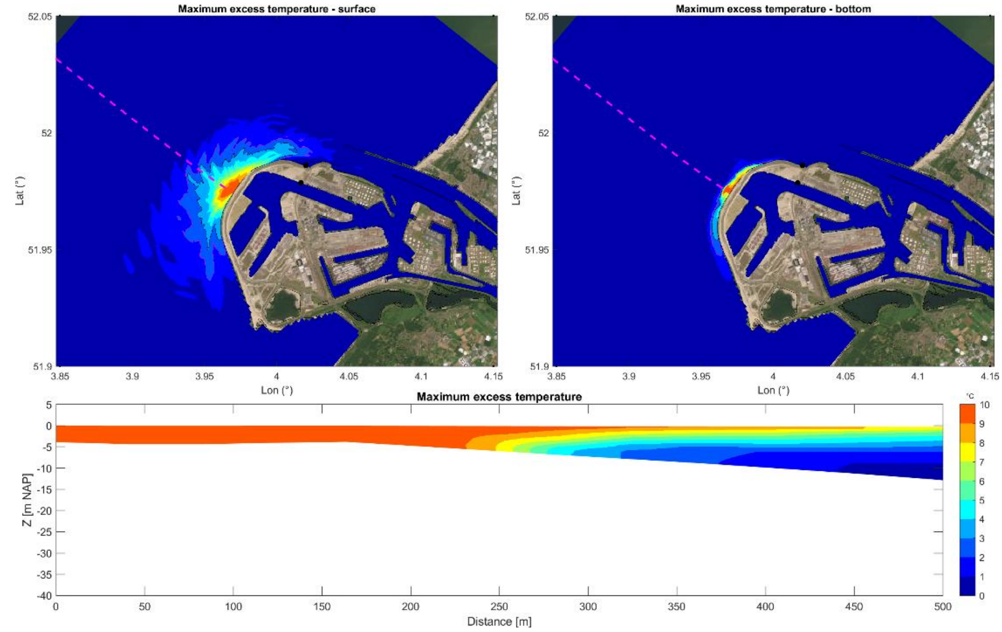

Figure C.17 Max temperature footprint Case 8, 6000 MWth, configuration 5 – discharge case 2, DT=9 °C (Zoom 1).

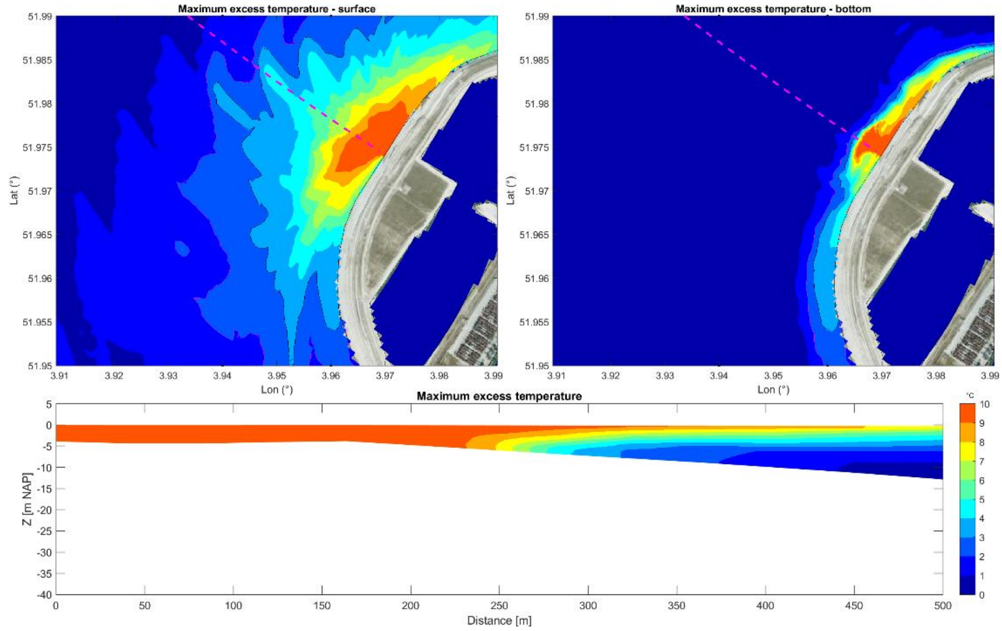

Figure C.18 Max temperature footprint Case 8, 6000 MWth, configuration 5 – discharge case 2, DT=9 °C (Zoom 2).

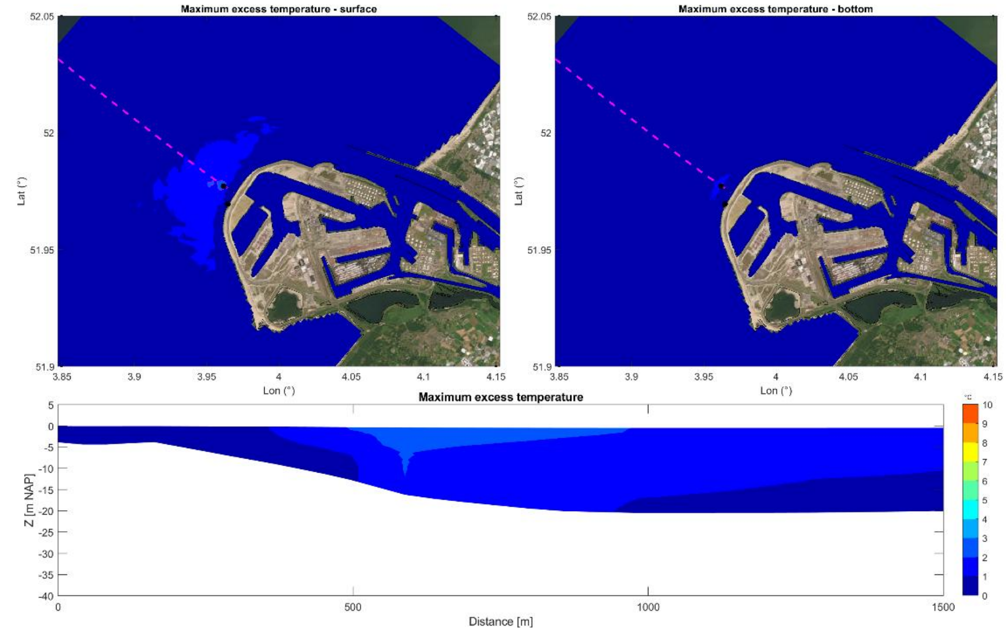

Figure C.19 Max temperature footprint Case 9, 6000 MWth, configuration 6 – discharge case 2, DT=9 °C (Zoom 1).

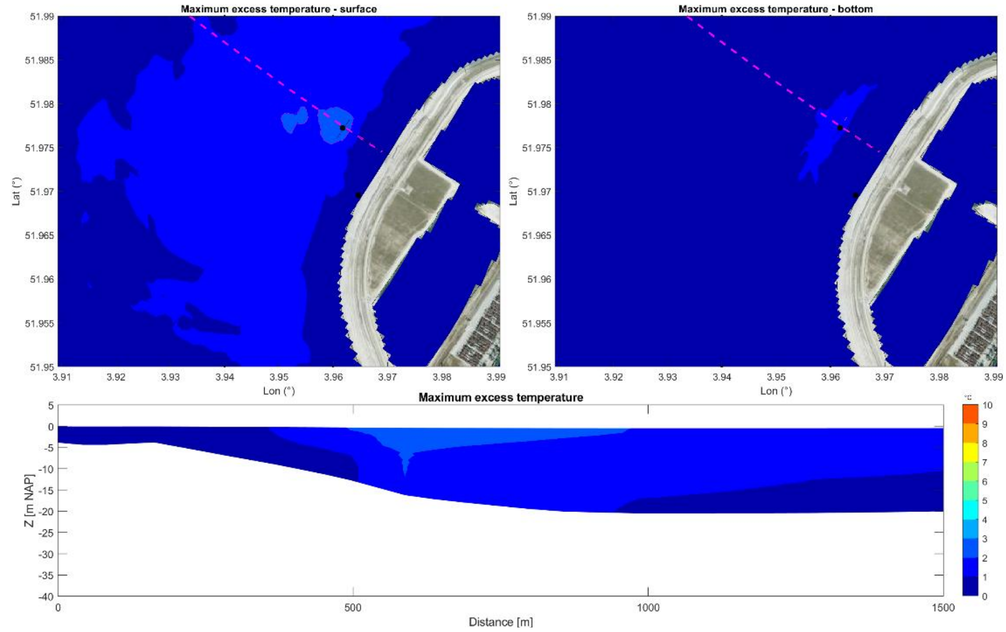

Figure C.20 Max temperature footprint Case 9, 6000 MWth, configuration 6 – discharge case 2, DT=9 °C (Zoom 2).

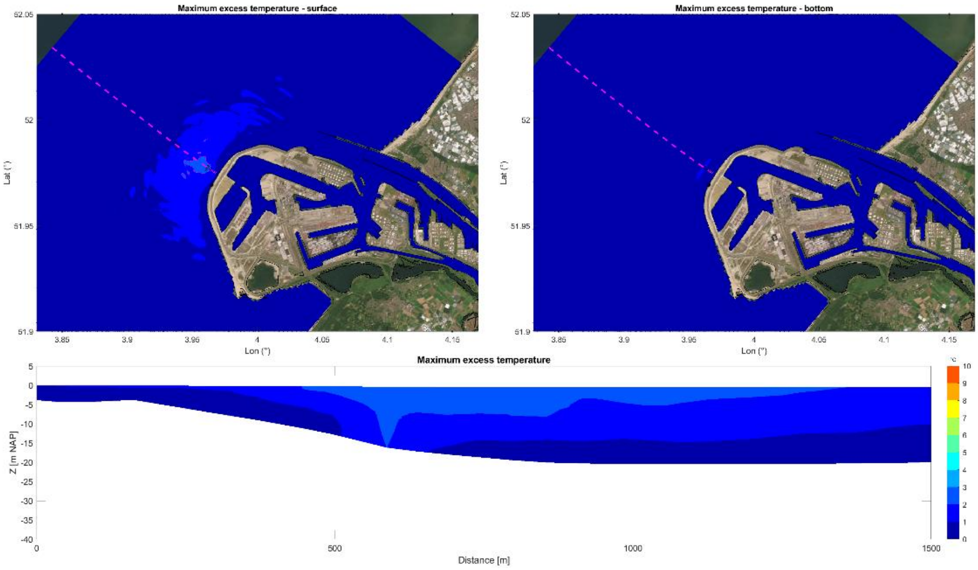

Figure C.21 Max temperature footprint Case 9b, 6000 MWth, configuration 6 – discharge case 3, DT=12 °C (Zoom 1).

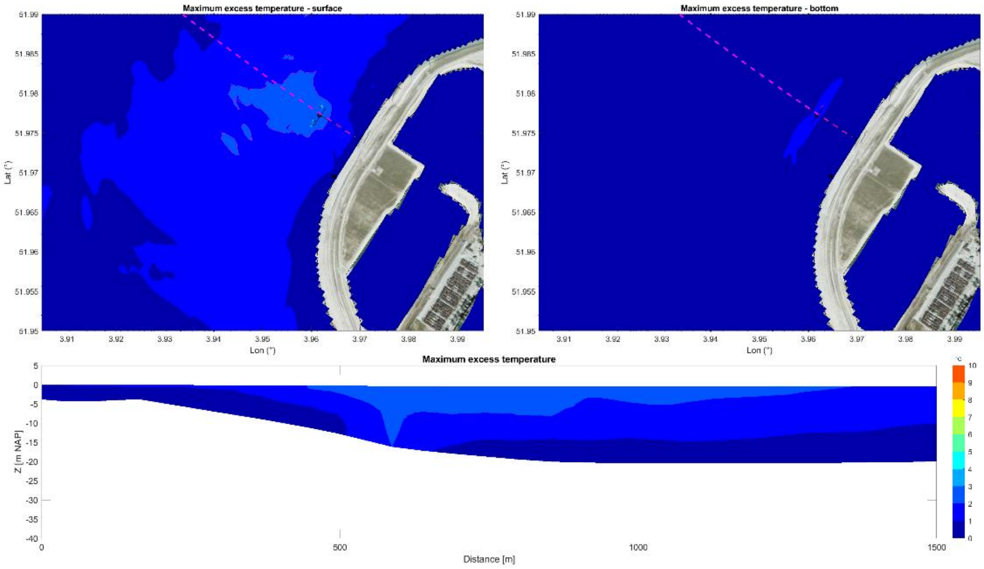

Figure C.22 Max temperature footprint Case 9b, 6000 MWth, configuration 6 – discharge case 3, DT=12 °C (Zoom 1).

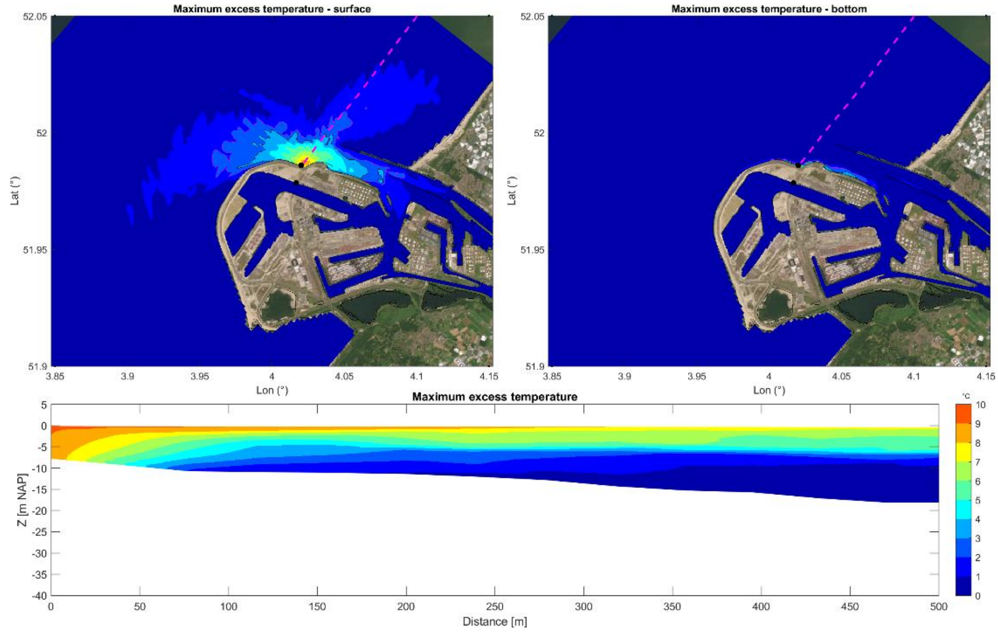

Figure C.23 Max temperature footprint Case 10, 6000 MWth, configuration 1 – discharge case 2, DT=9 °C, modified stratification at the model boundaries (Zoom 1).

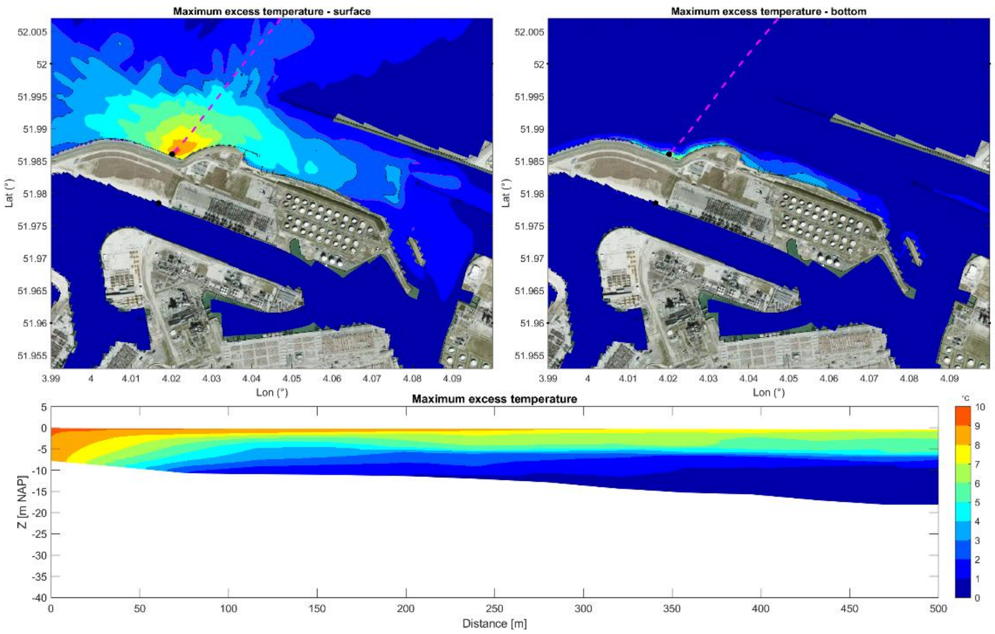

Figure C.24 Max temperature footprint Case 10, 6000 MWth, configuration 1 – discharge case 2, DT=9 °C, modified stratification at the model boundaries (Zoom 2).

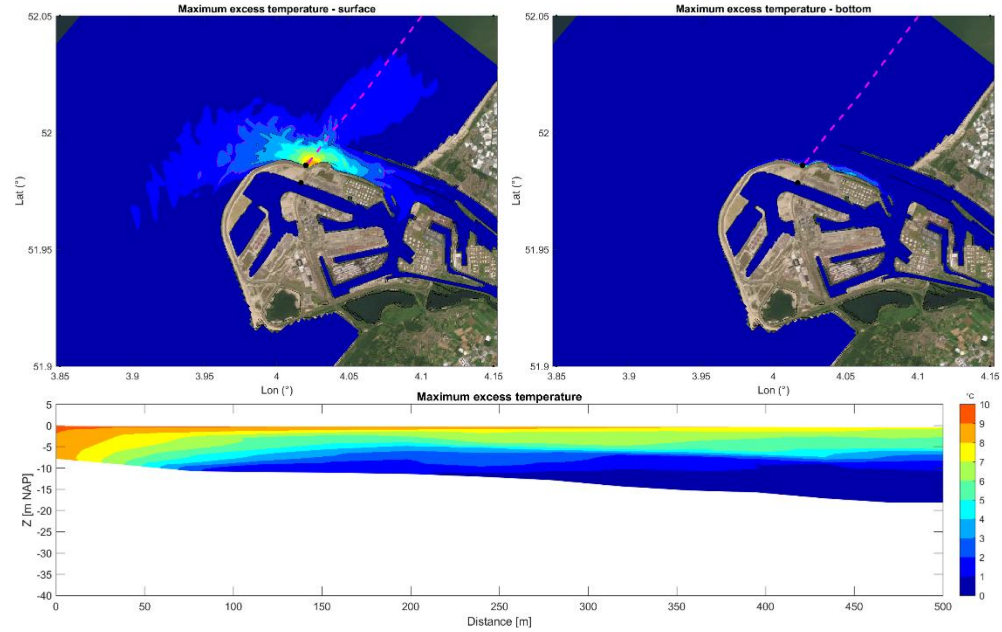

Figure C.25 Max temperature footprint Case 11, 6000 MWth, configuration 1 – discharge case 2, DT=9 °C, uniform fresh water at the eastern model boundary (Zoom 1).

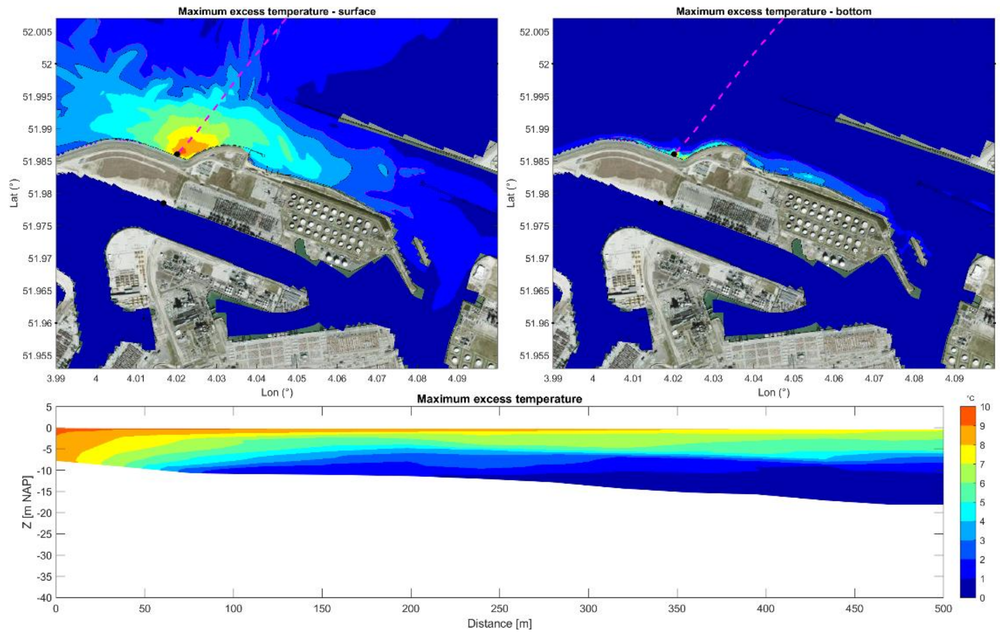

Figure C.26 Max temperature footprint Case 11, 6000 MWth, configuration 1 – discharge case 2, DT=9 °C, uniform fresh water at the eastern model boundary (Zoom 2).

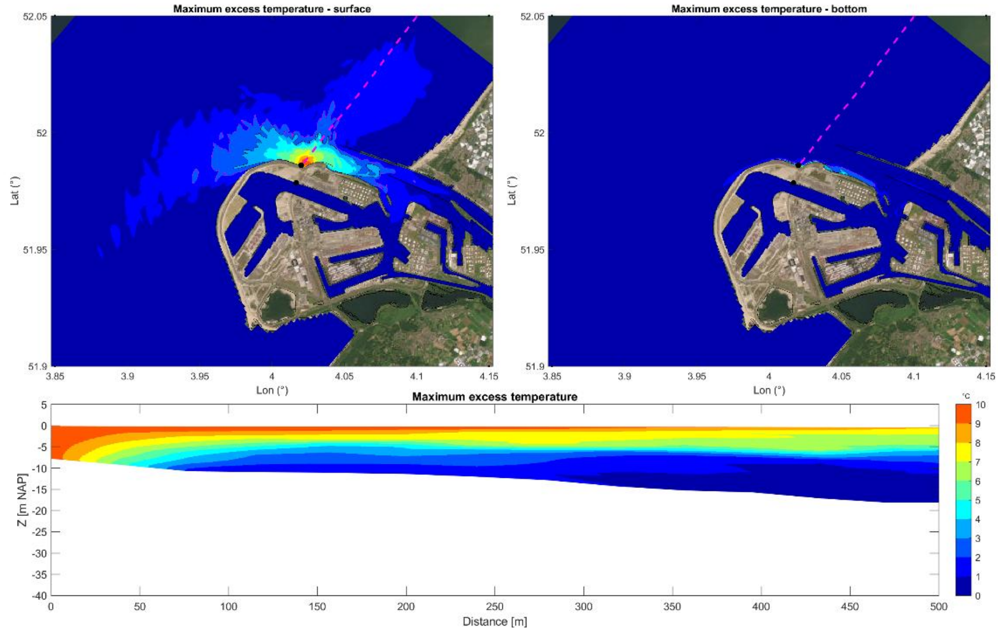

Figure C.27 Max temperature footprint Case 12, 6000 MWth, configuration 1 – discharge case 2, DT=10 °C (Zoom 1).

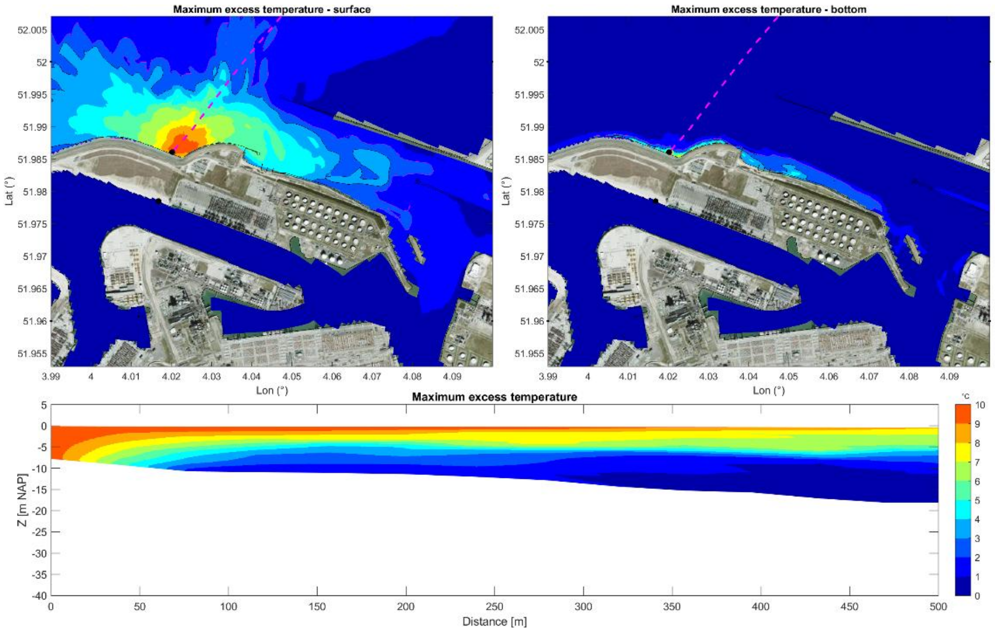

Figure C.28 Max temperature footprint Case 12, 6000 MWth, configuration 1 – discharge case 2, DT=10 °C (Zoom 2).

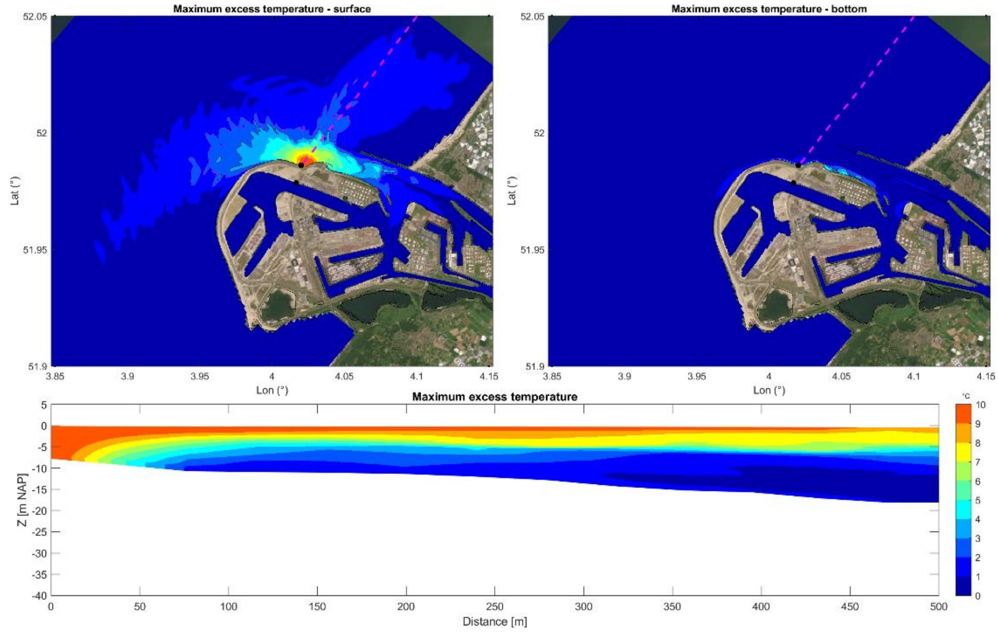

Figure C.29 Max temperature footprint Case 13, 6000 MWth, configuration 1 – discharge case 2, DT=11 °C (Zoom 1).

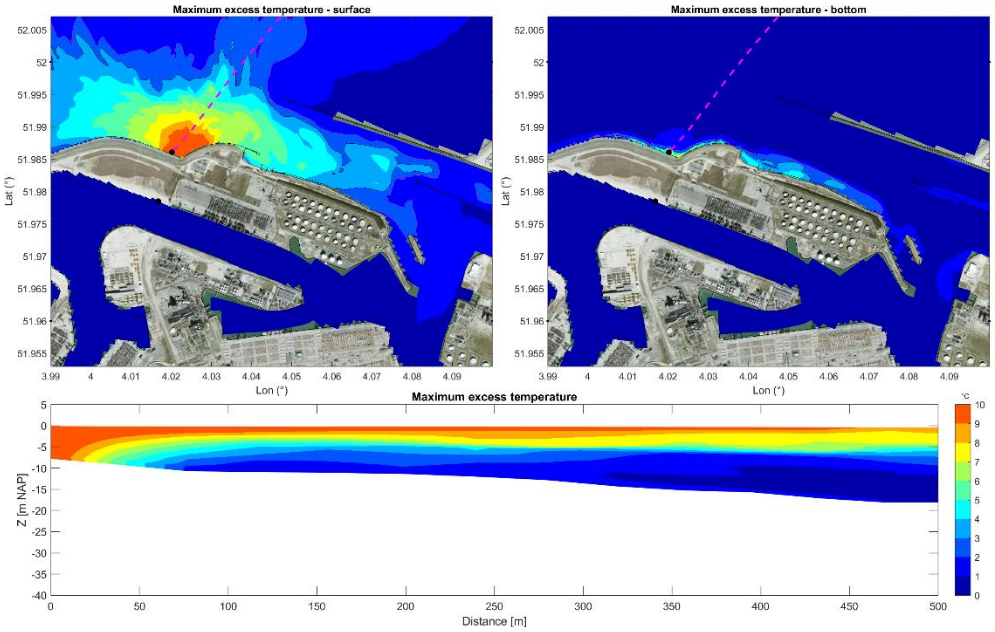

Figure C.30 Max temperature footprint Case 13, 6000 MWth, configuration 1 – discharge case 2, DT=11°C (Zoom 1).

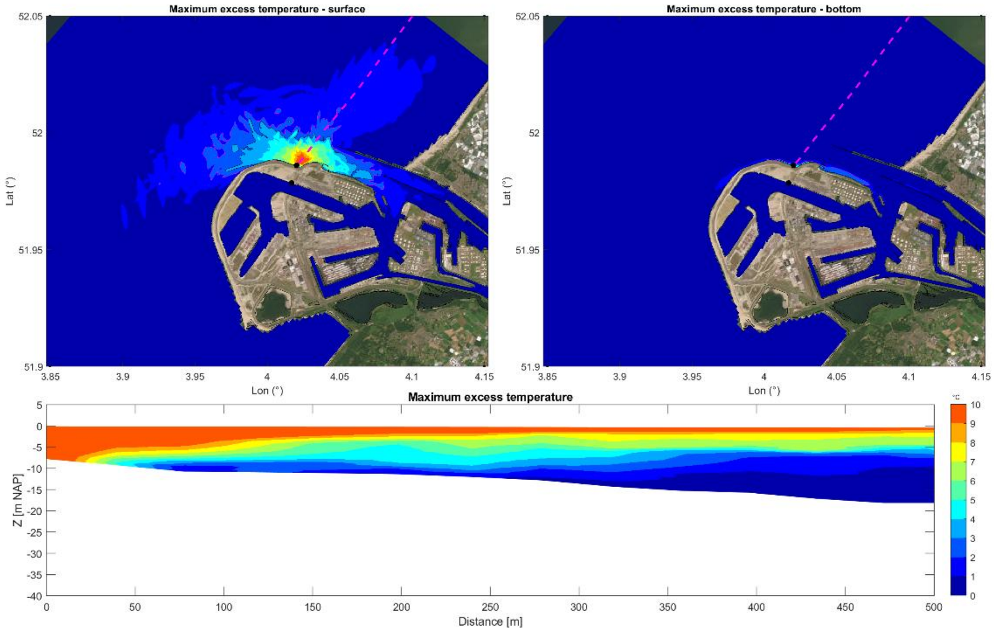

Figure C.31 Max temperature footprint Case 14, 6000 MWth, configuration 1 – discharge case 3, DT=12 °C, including breakwaters (Zoom 1).

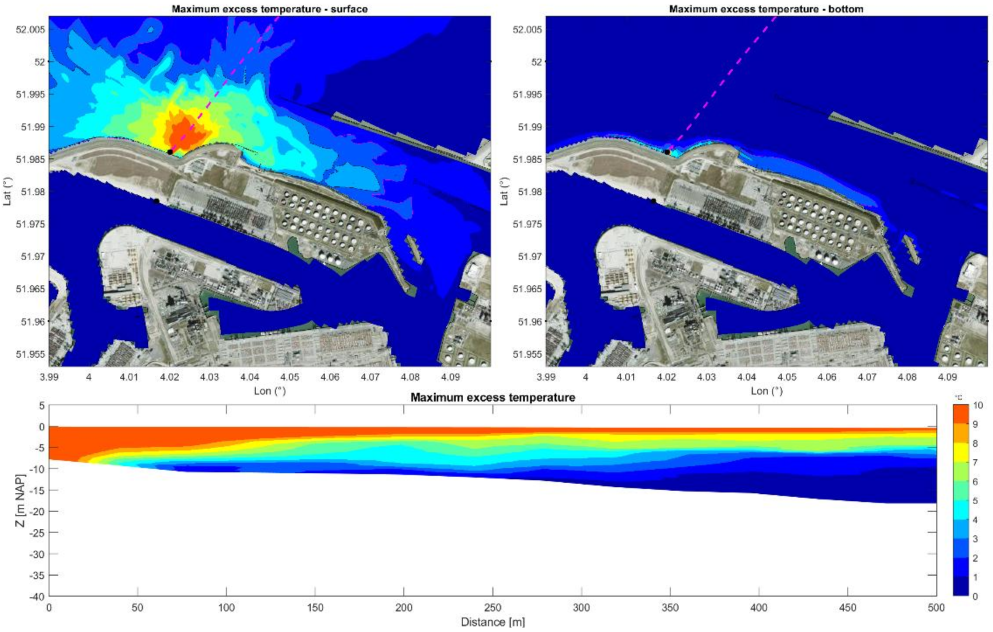

Figure C.32 Max temperature footprint Case 14, 6000 MWth, configuration 1 – discharge case 3, DT=12 °C, including breakwaters (Zoom 2).

D CIW mixing zone and average temperature increase criterion

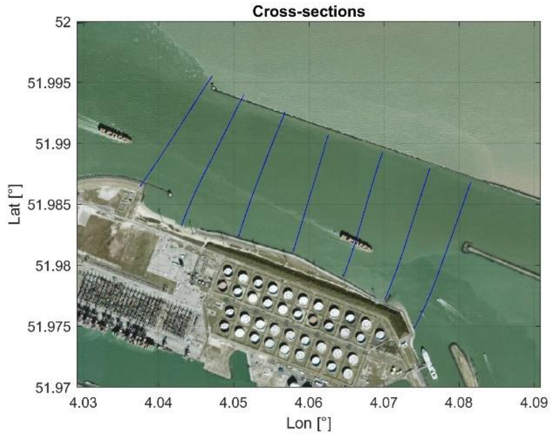

Figure D.1 Cross section 1 covers the Maasmond area to compute the CIW average temperature criteria.

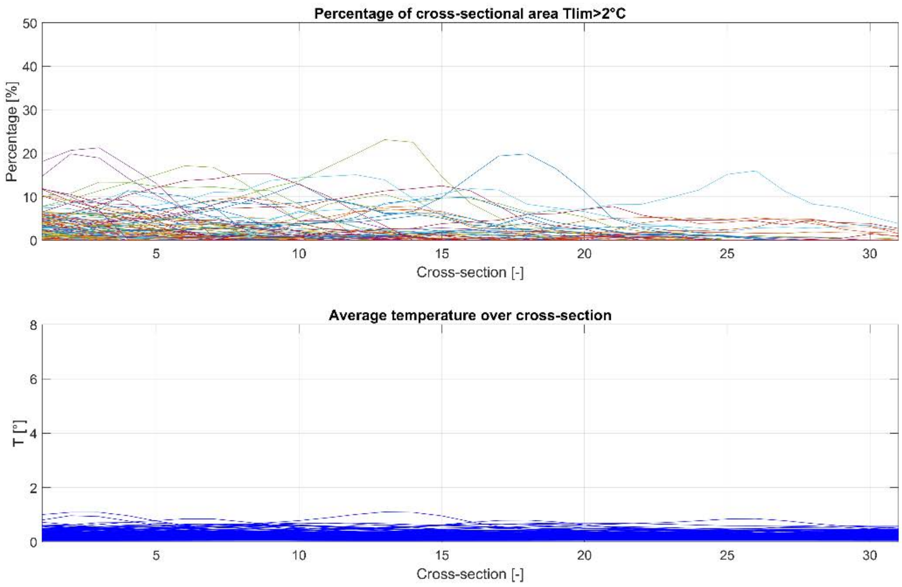

Figure D.2 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 1.

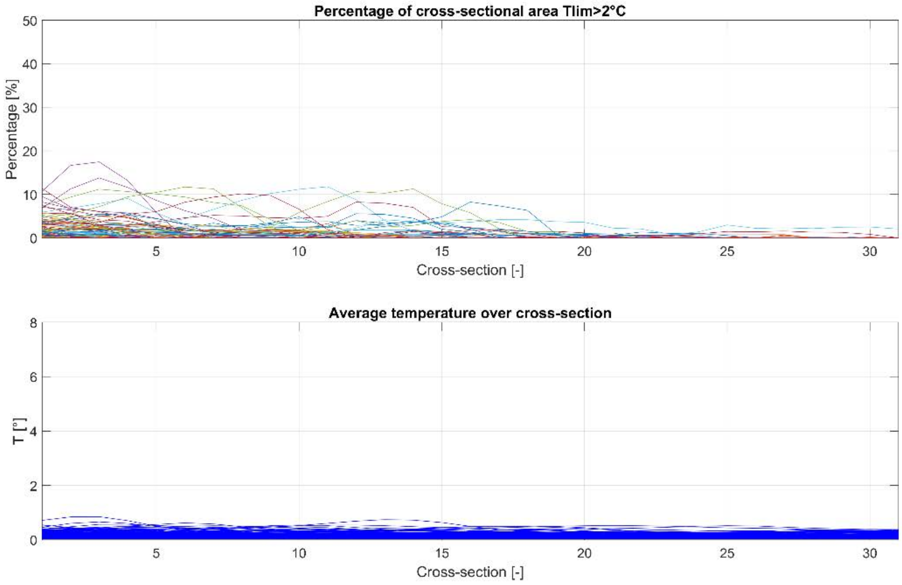

Figure D.3 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 2.

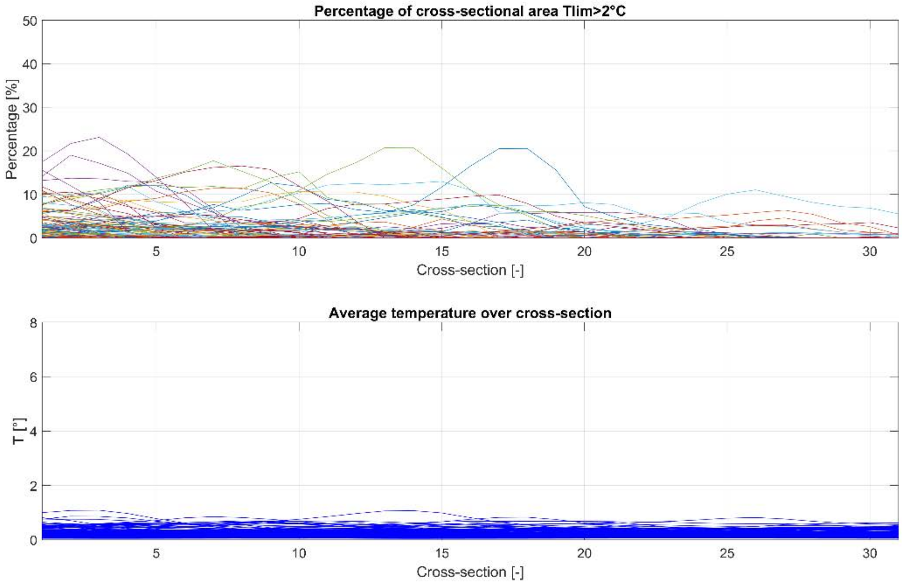

Figure D.4 Figure 6-1 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 3.

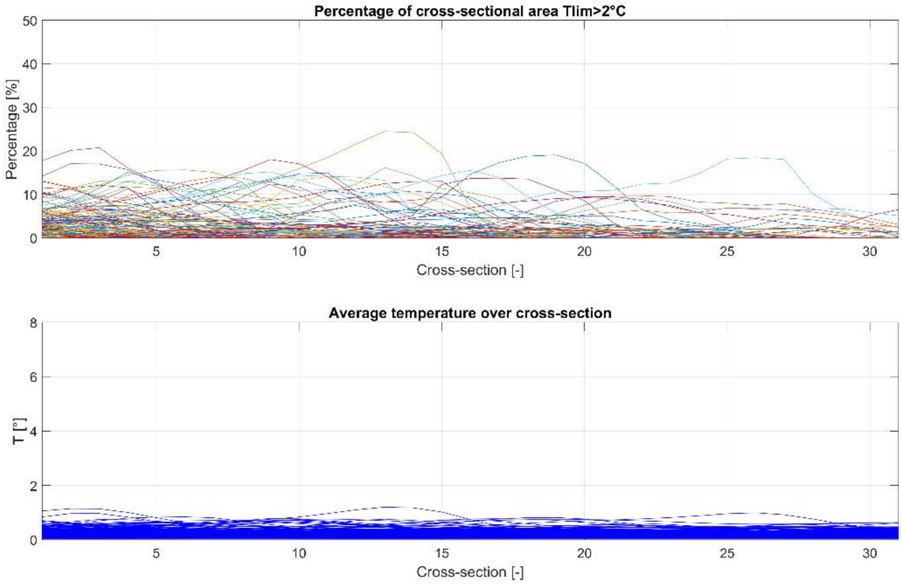

Figure D.5 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 4.

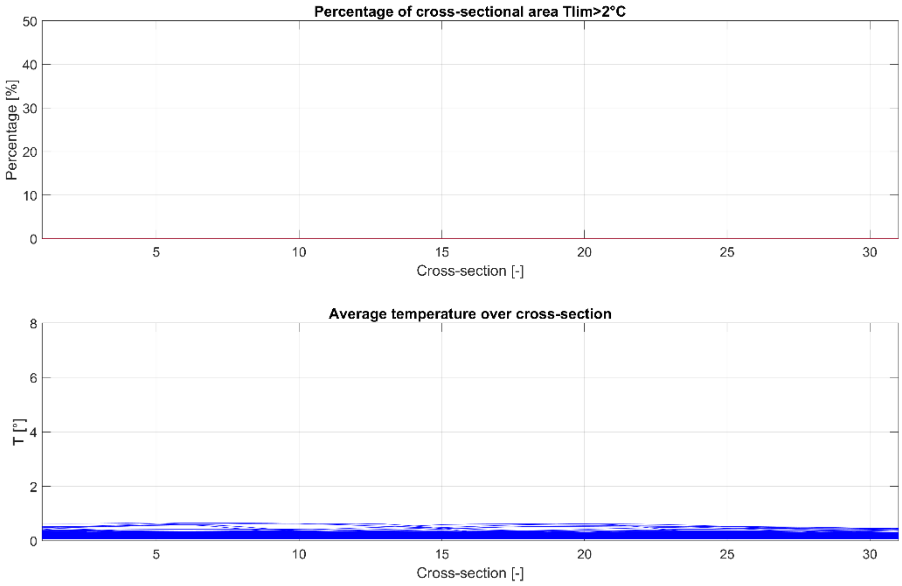

Figure D.6 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 5.

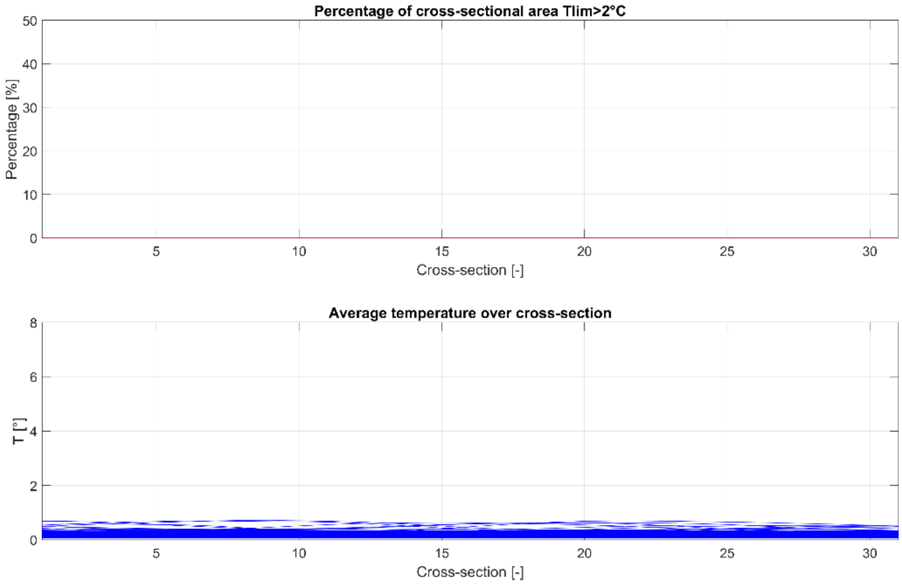

Figure D.7 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 5b.

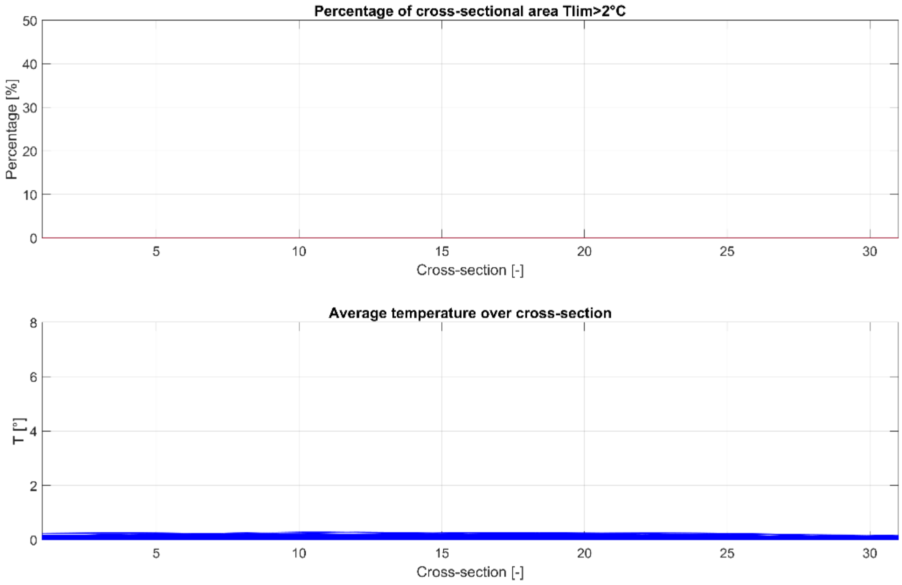

Figure D.8 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 6.

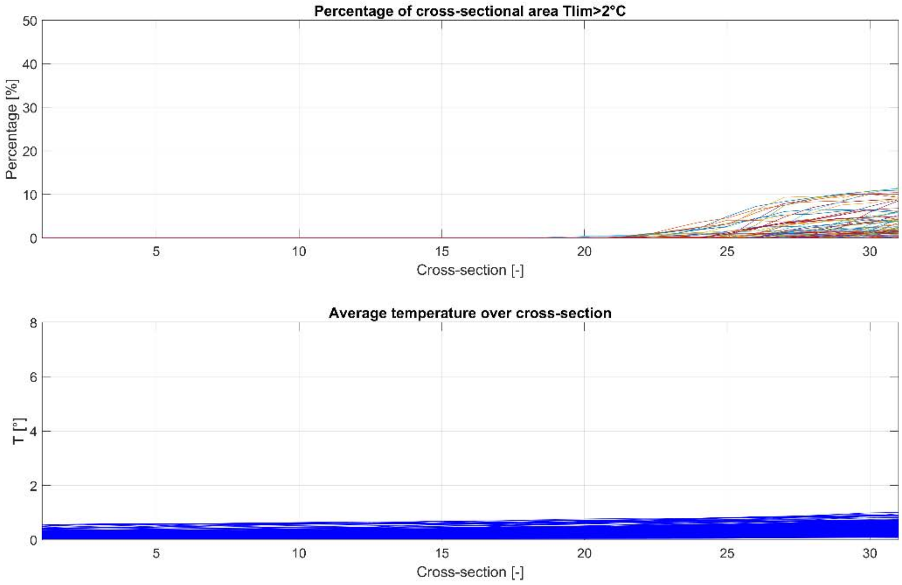

Figure D.9 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 7.

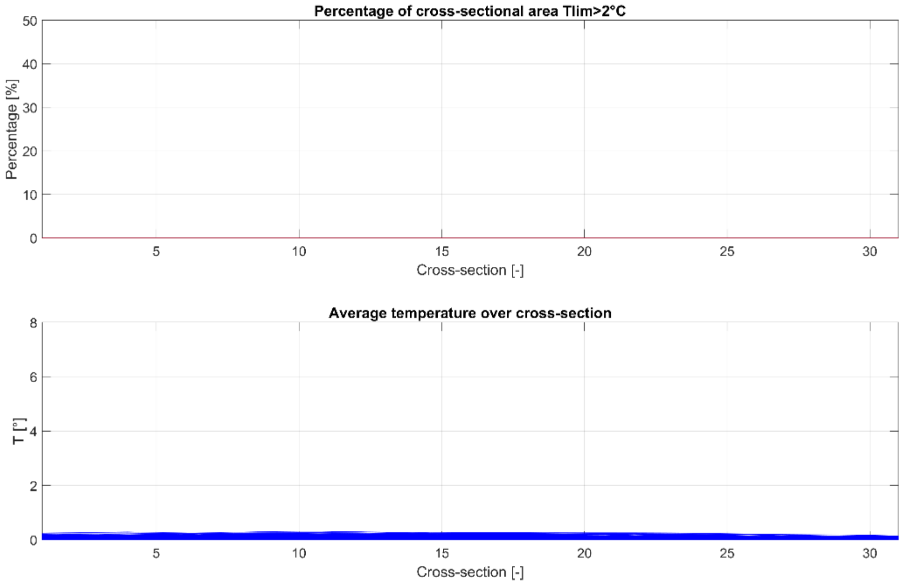

Figure D.10 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 8.

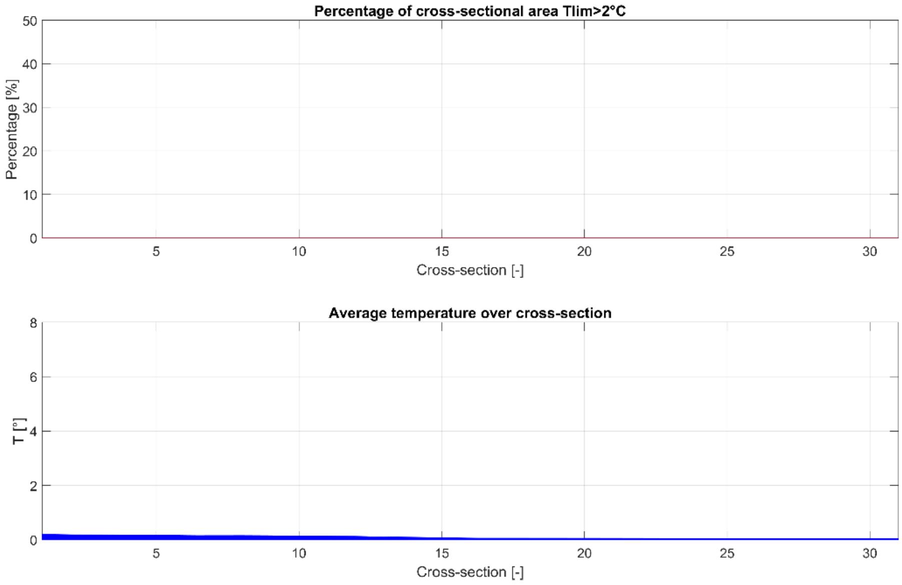

Figure D.11 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 9.

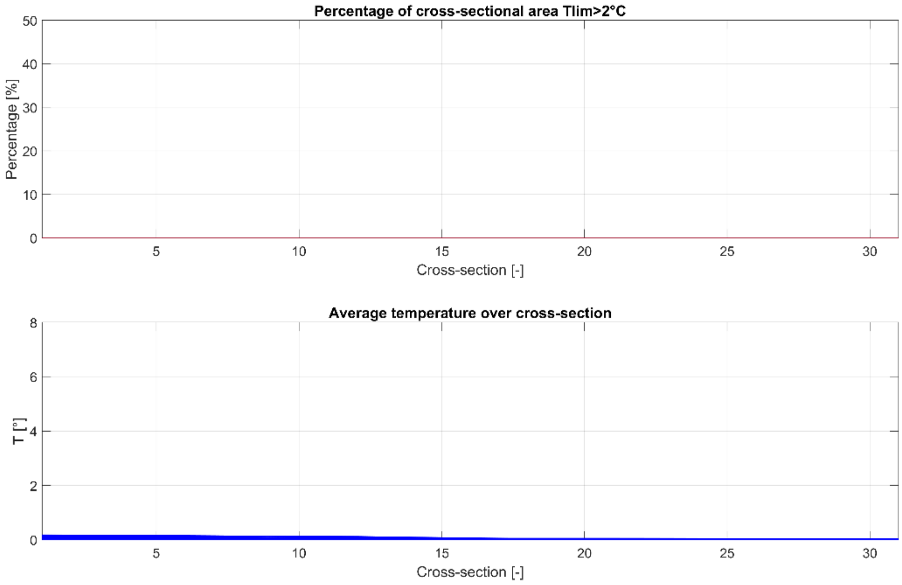

Figure D.12 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 9b.

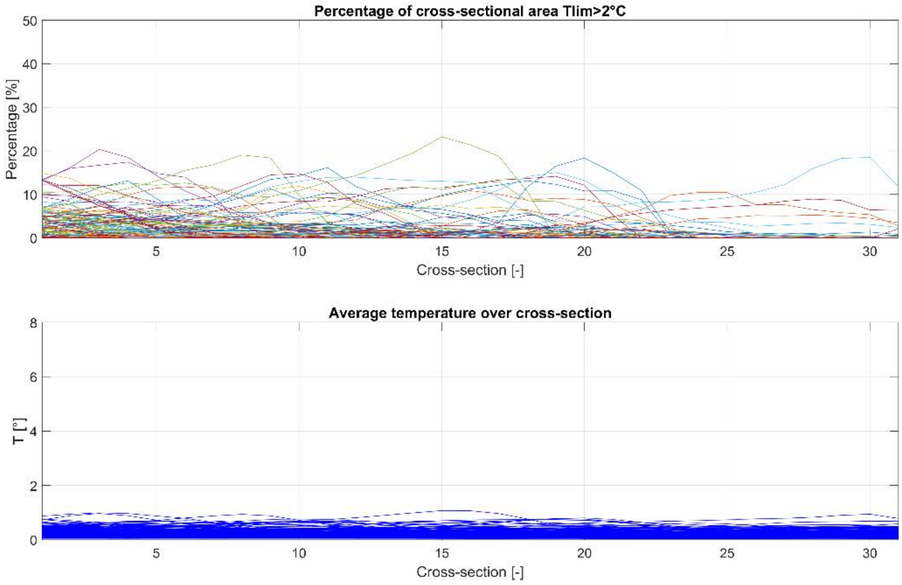

Figure D.13 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 10.

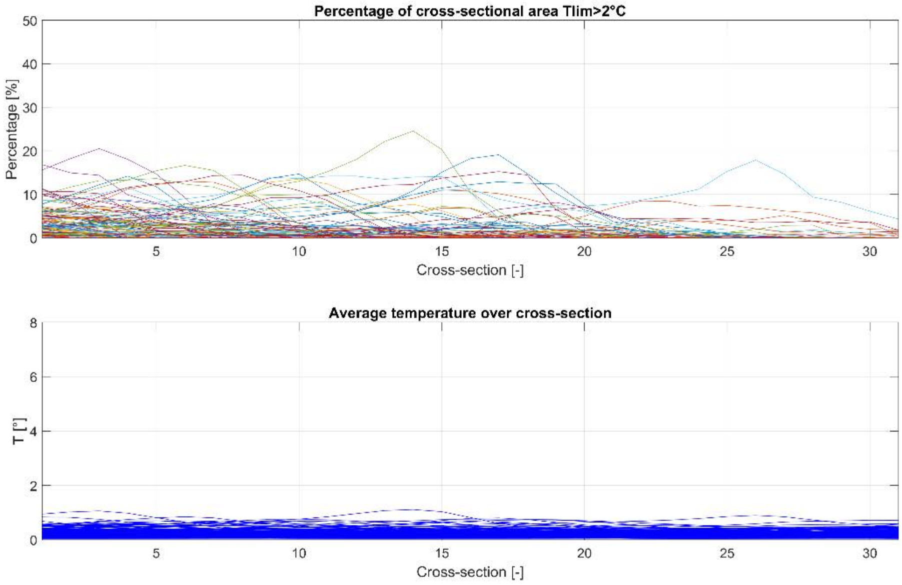

Figure D.14 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 11.

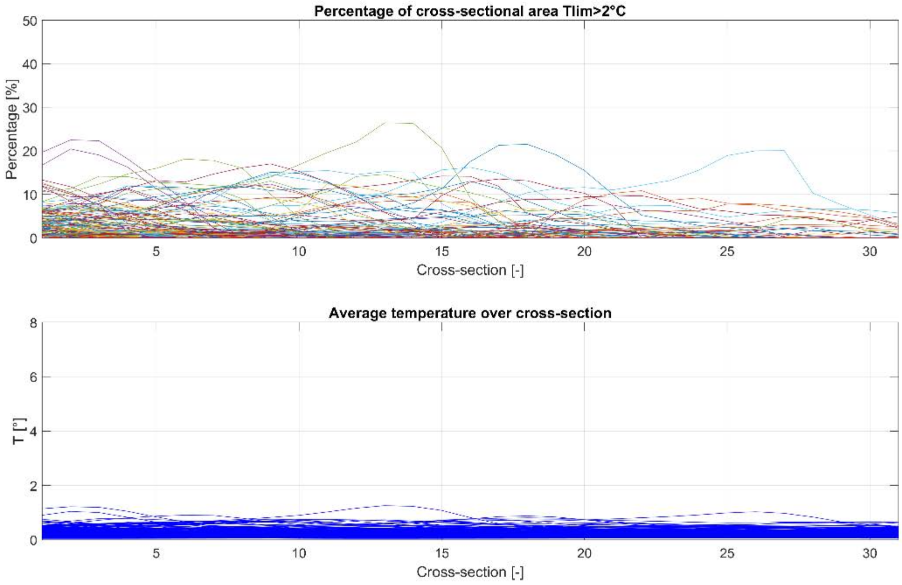

Figure D.15 *Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 12.*

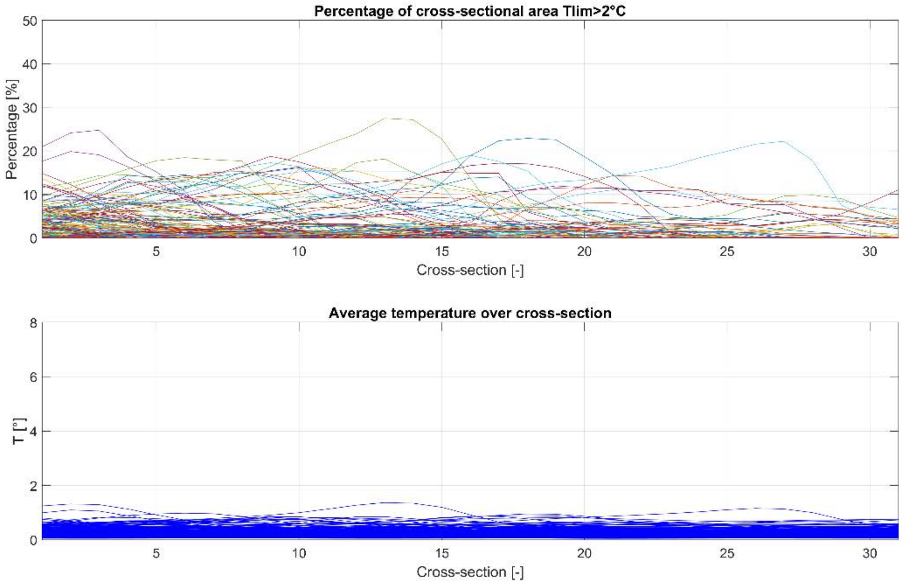

Figure D.16 *Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 13.*

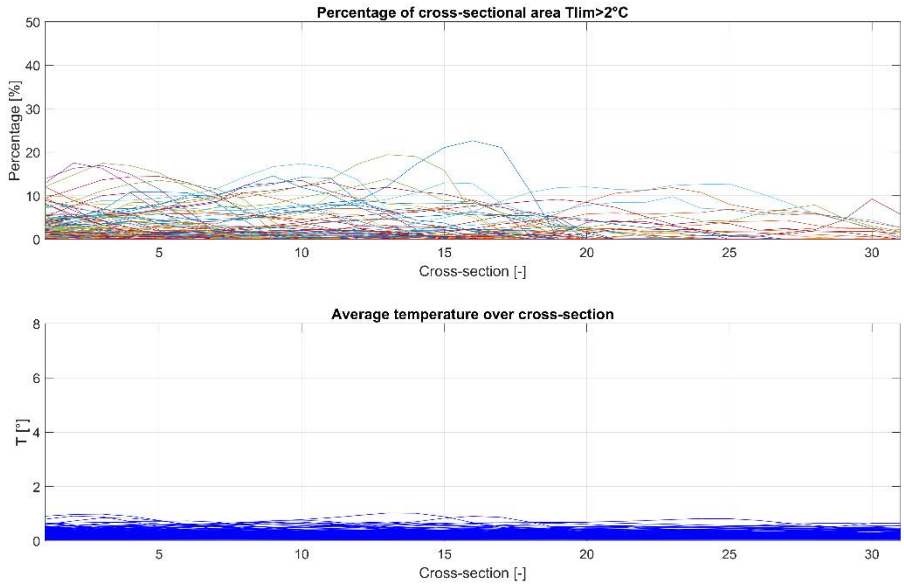

Figure D.17 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 1 area (Maasmond area) - Case 14.

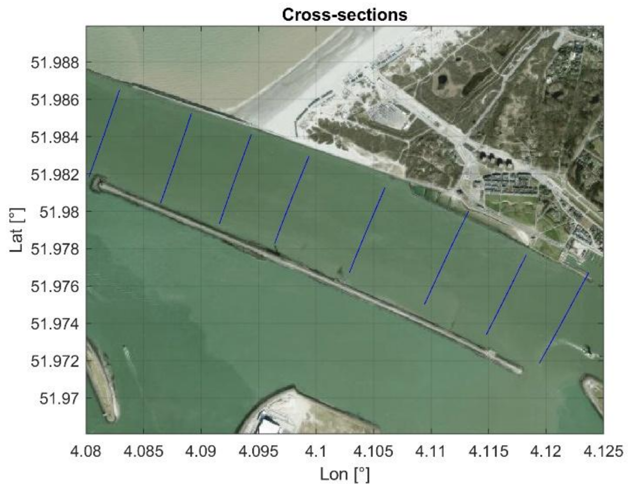

Figure D.18 Cross section 2 covers the north-east side from the Maasmond area towards the Nieuwe Waterweg to compute the CIW temperature criteria.

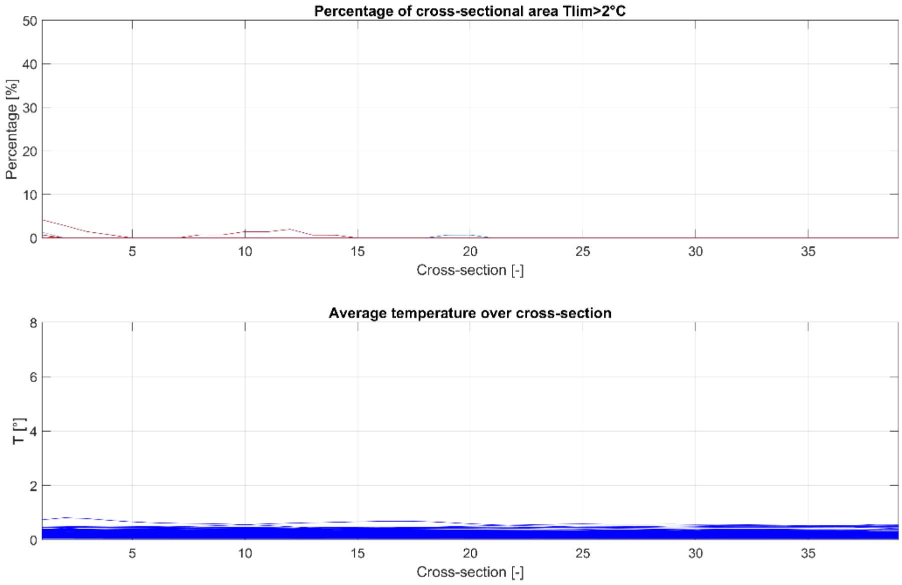

Figure D.19 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 1.

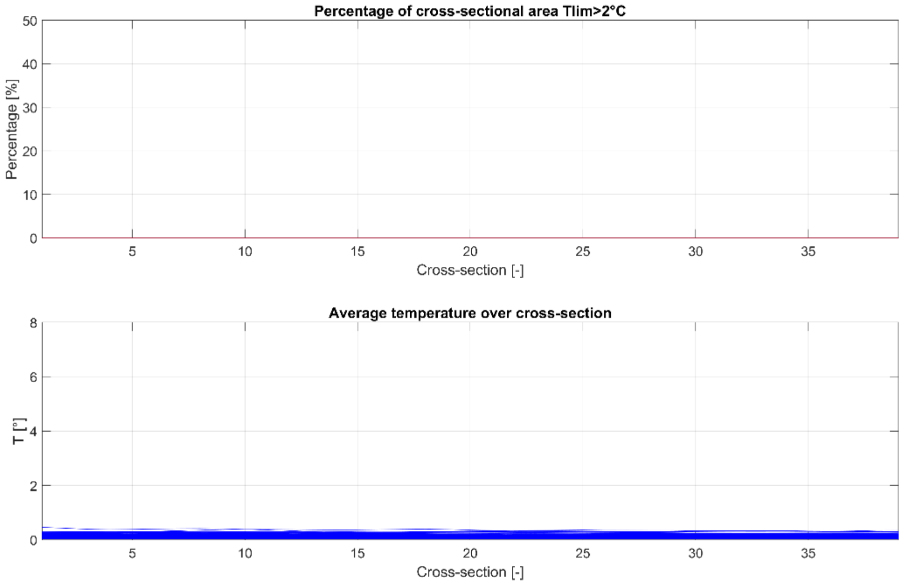

Figure D.20 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 2.

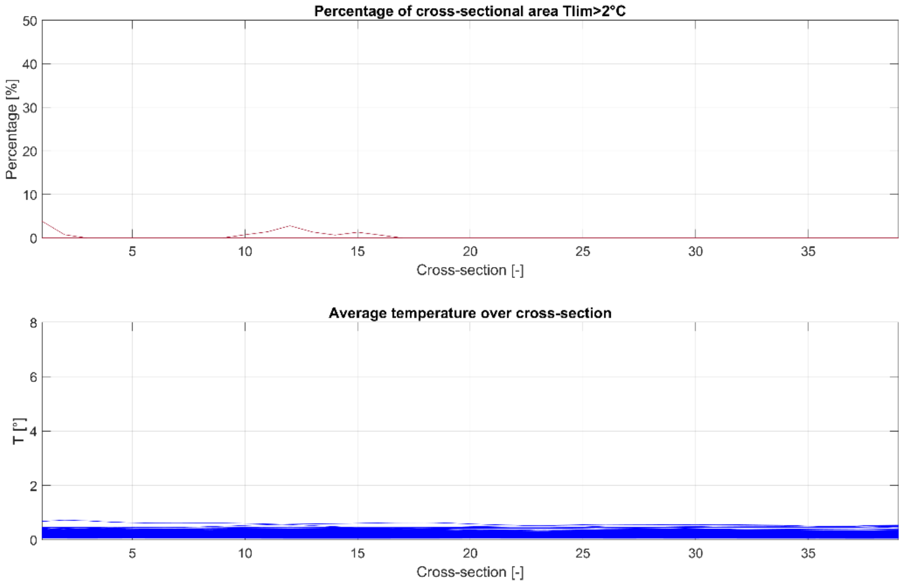

Figure D.21 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 3.

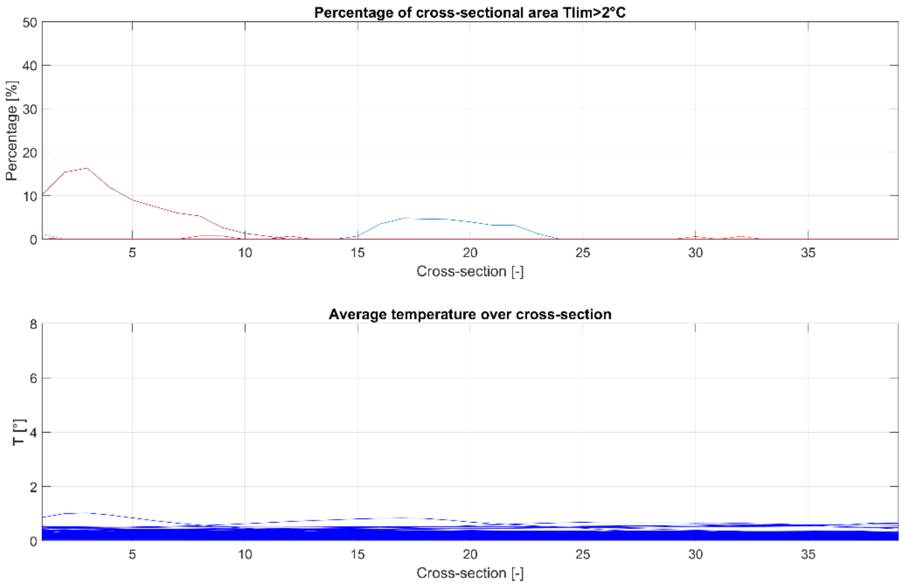

Figure D.22 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 4.

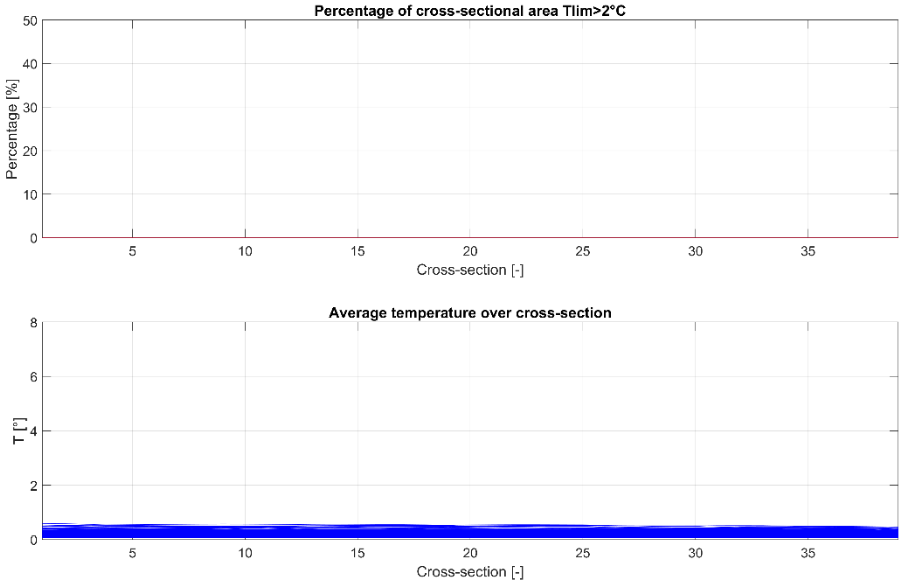

Figure D.23 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 5.

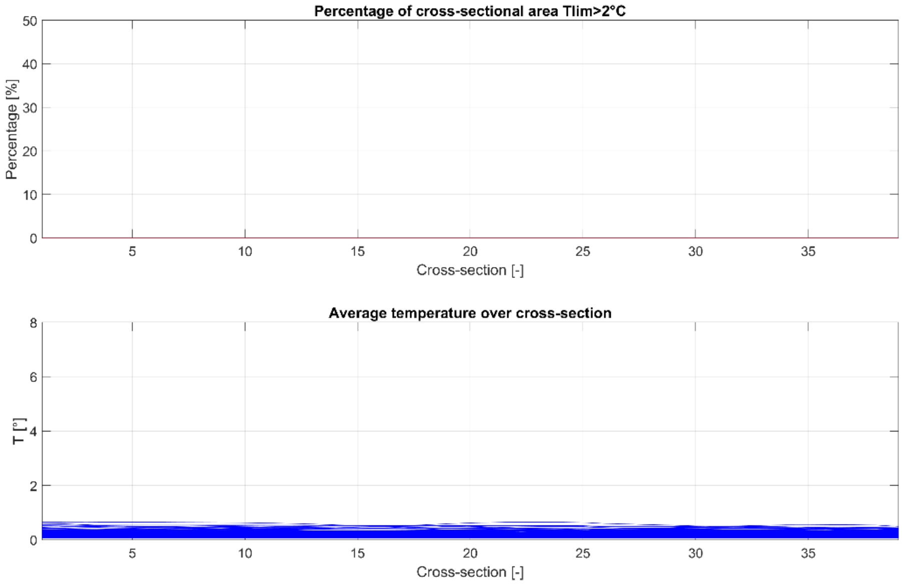

Figure D.24 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 5b.

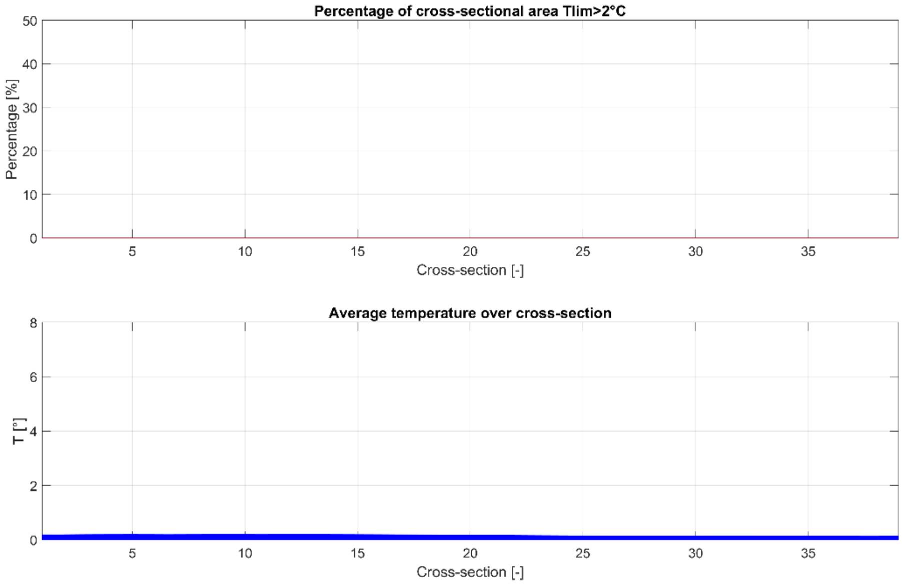

Figure D.25 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 6.

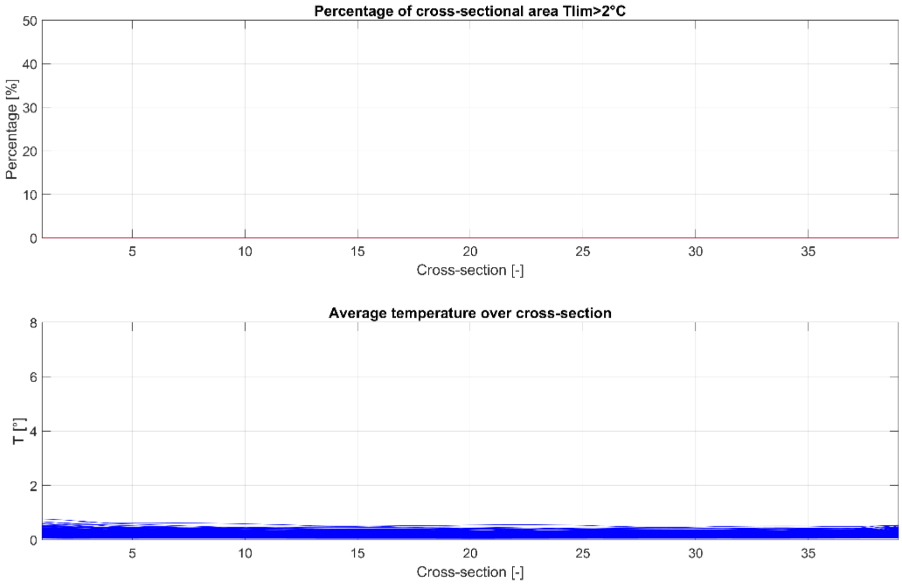

Figure D.26 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 7.

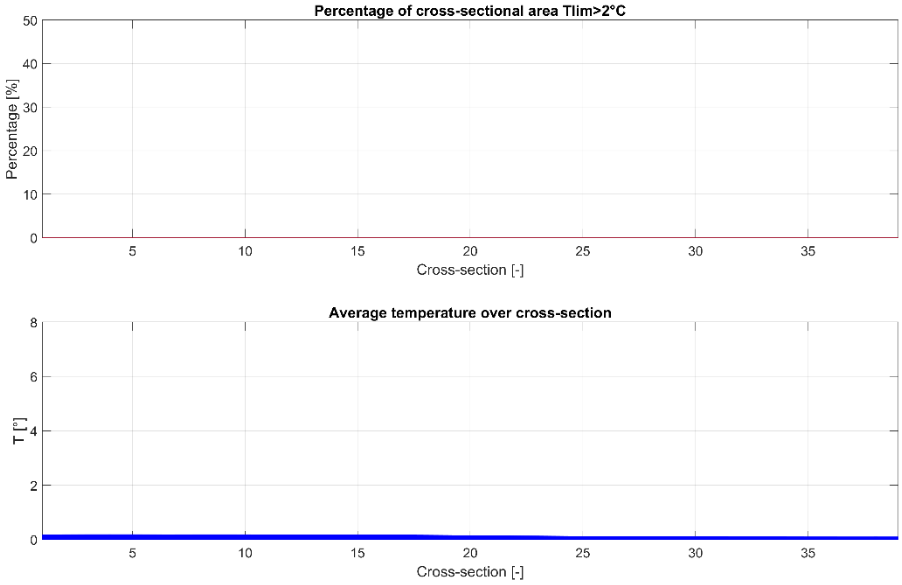

Figure D.27 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 8.

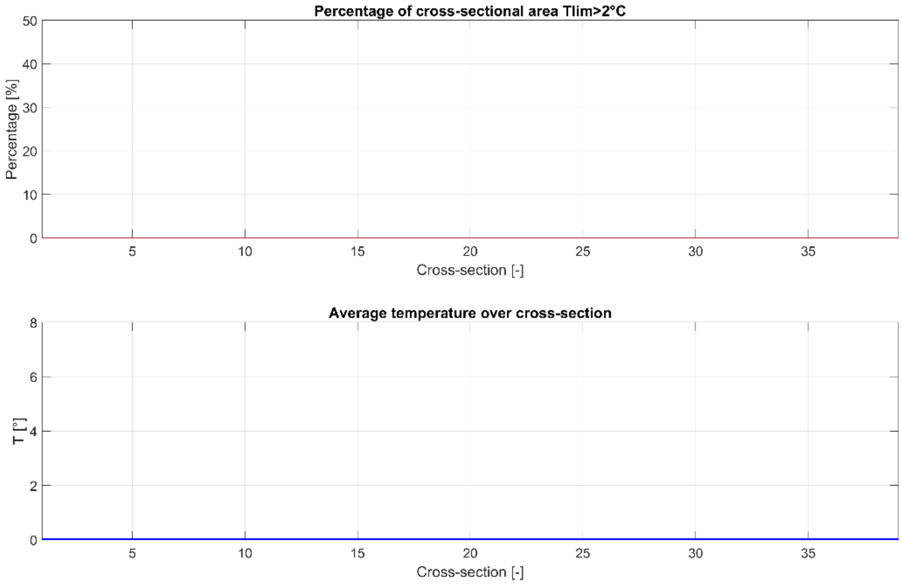

Figure D.28 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 9.

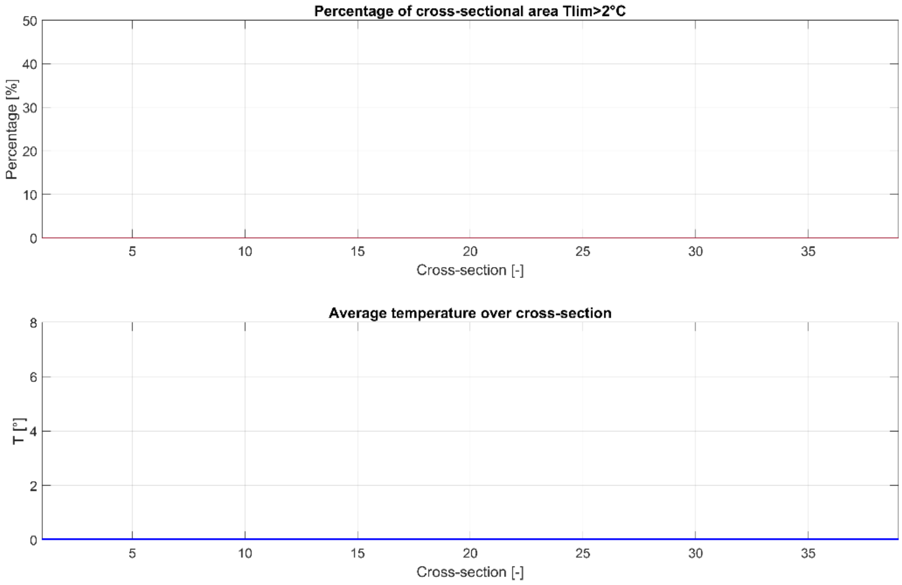

Figure D.29 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 9b.

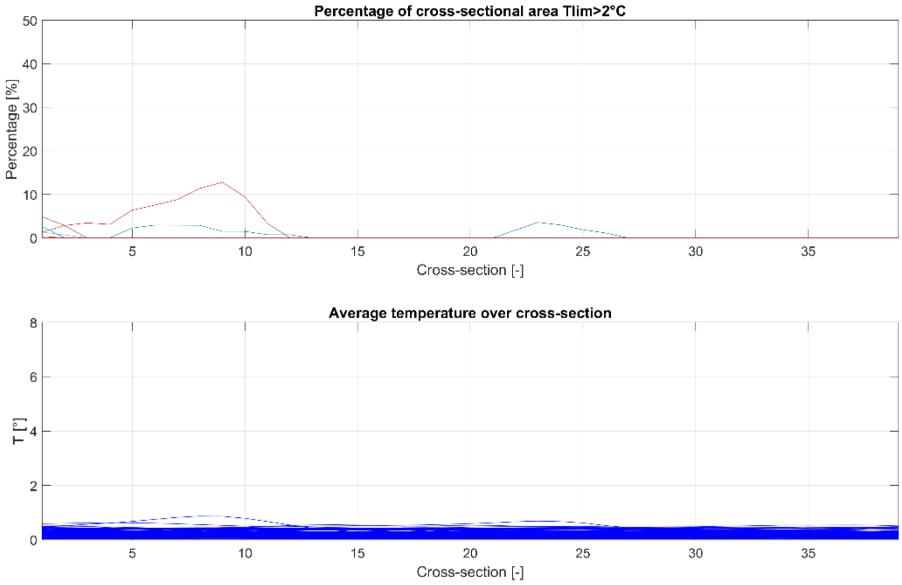

Figure D.30 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 10.

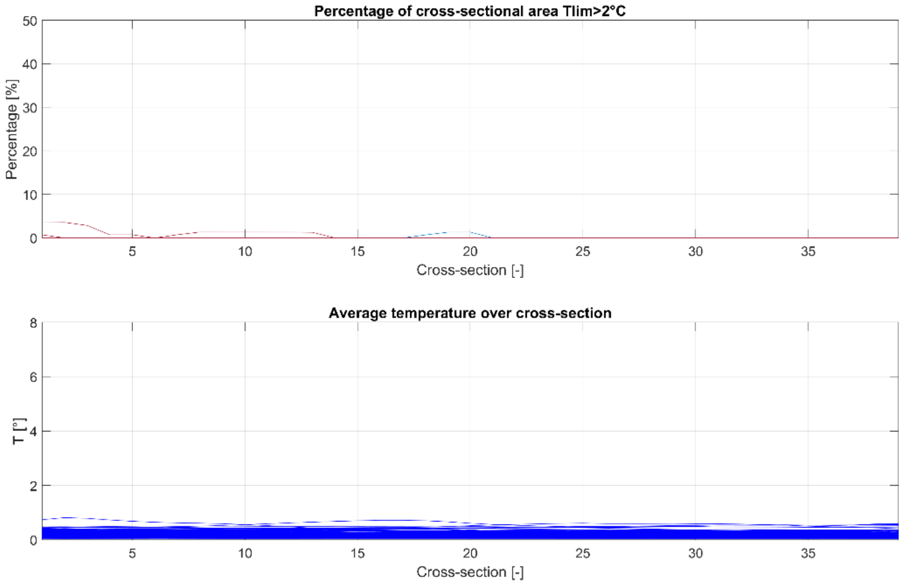

Figure D.31 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 11.

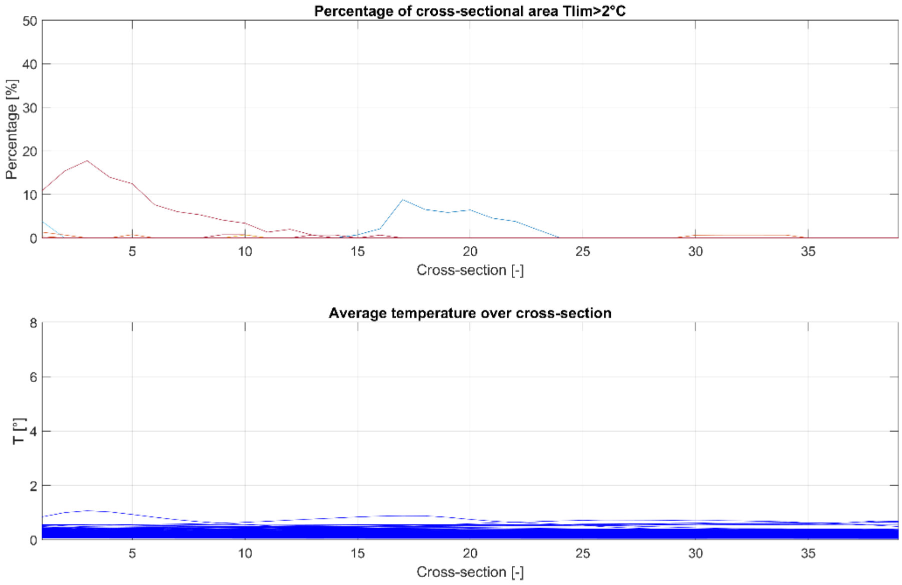

Figure D.32 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 12.

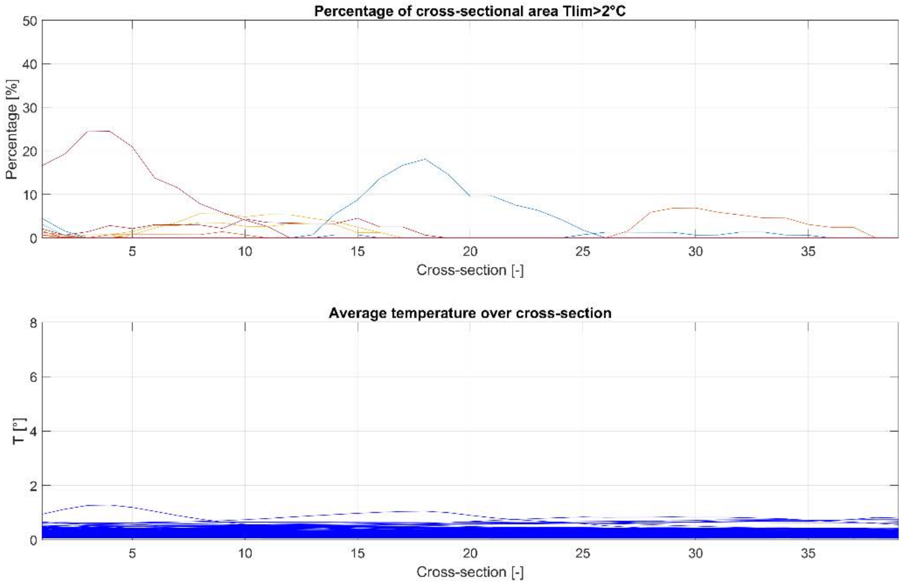

Figure D.33 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 13.

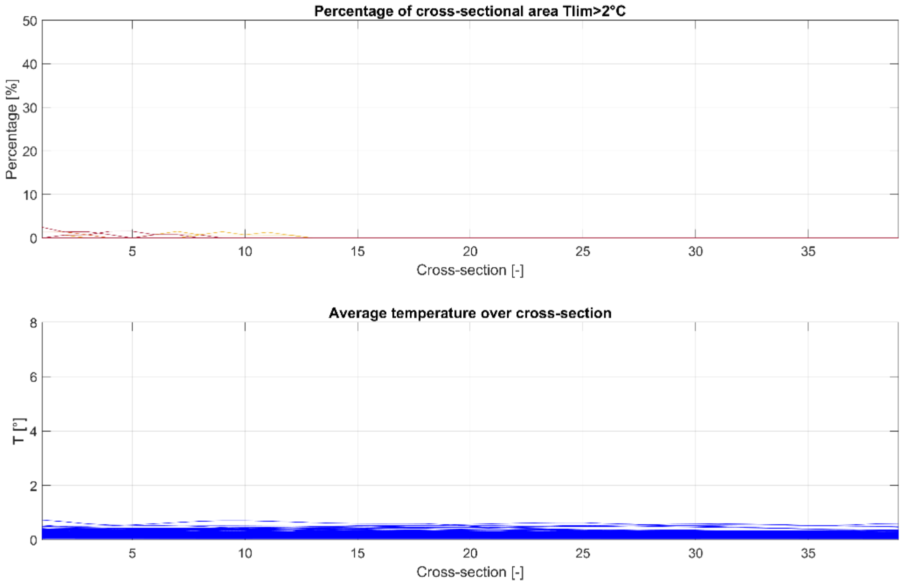

Figure D.34 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Nieuwe Waterweg area) - Case 14.

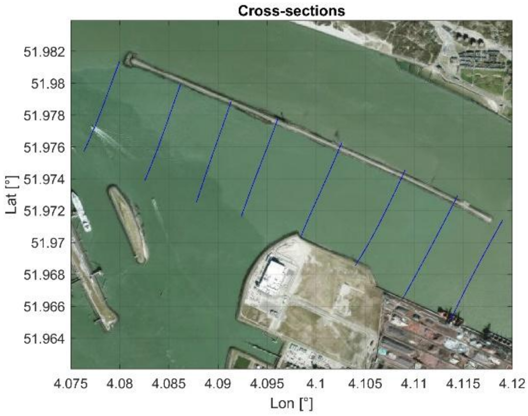

Figure D.35 Cross section 3 covers the south-east side from the Maasmond area towards the Calandkanaal to compute CIW temperature criteria.

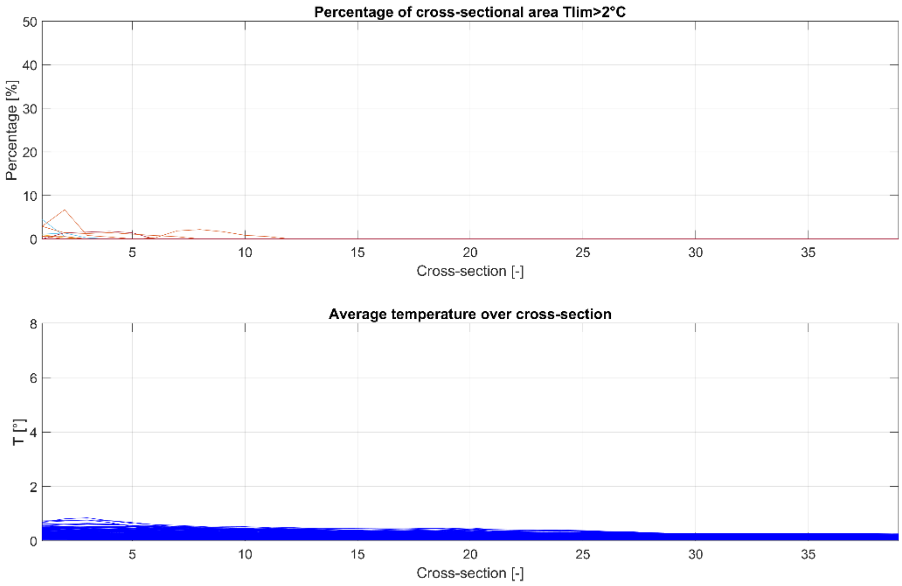

Figure D.36 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 1.

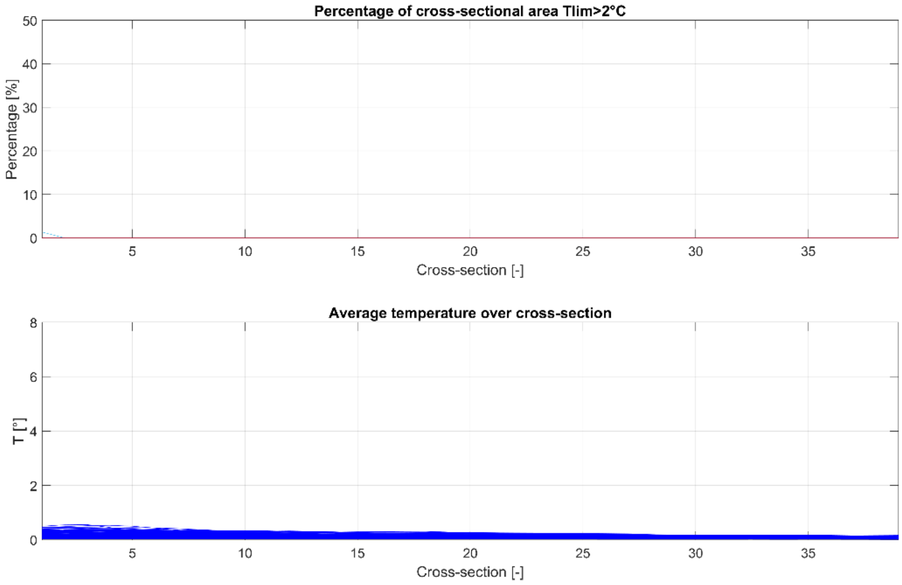

Figure D.37 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 2.

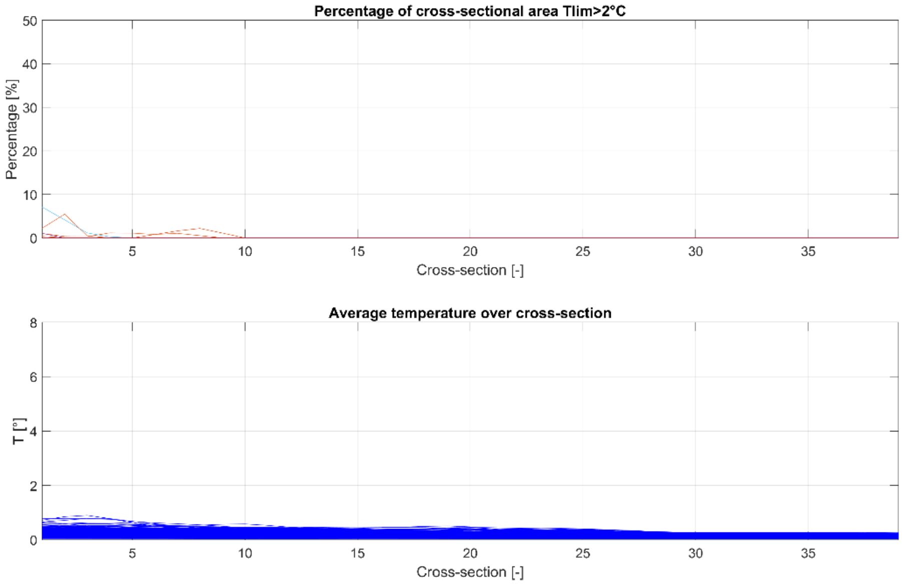

Figure D.38 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 3.

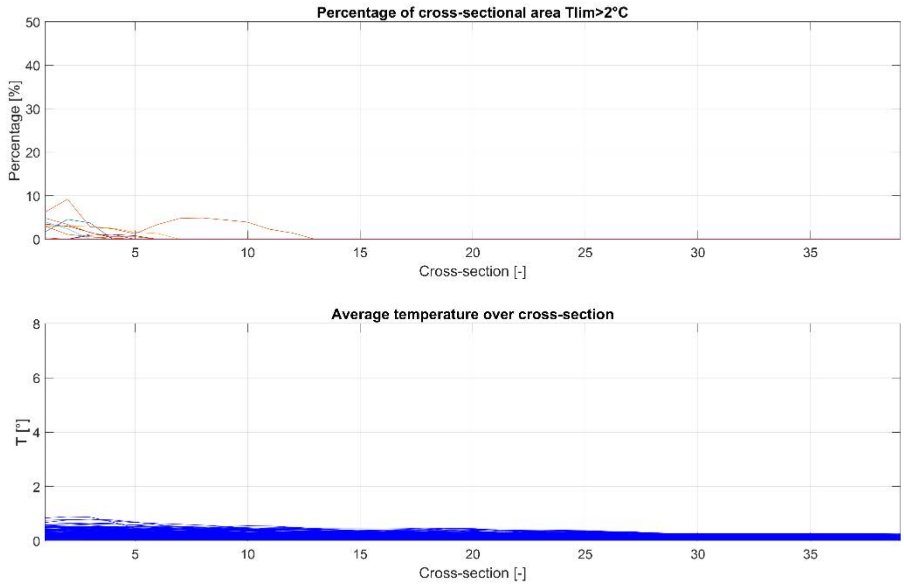

Figure D.39 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 4.

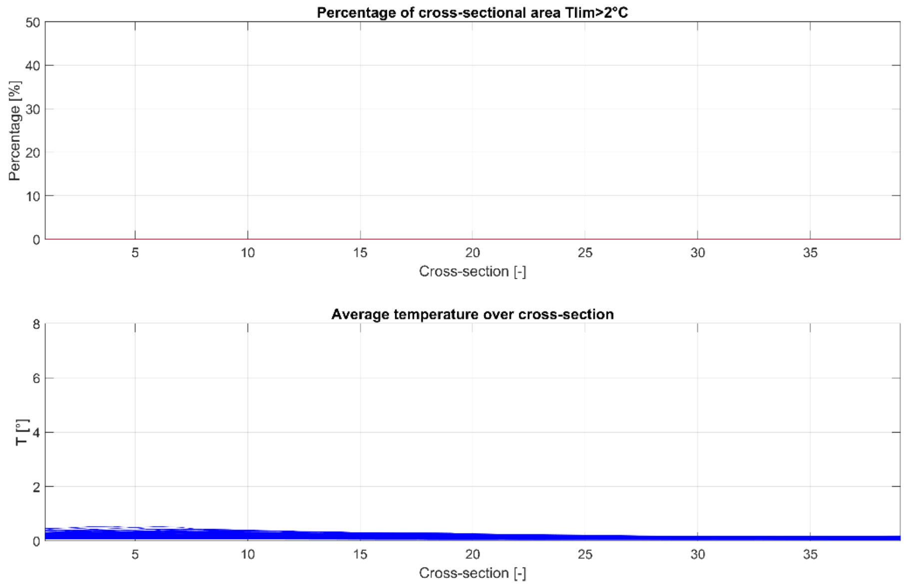

Figure D.40 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 5.

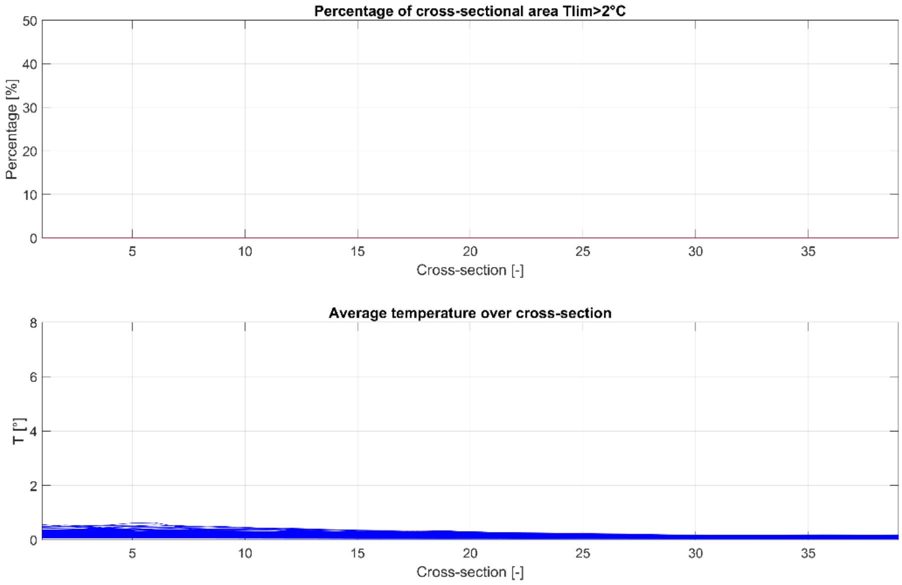

Figure D.41 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 5b.

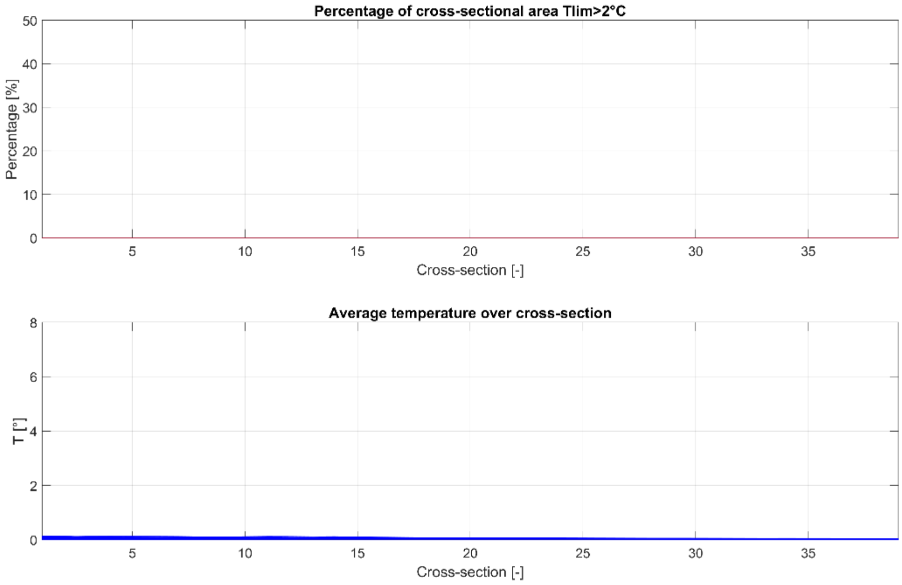

Figure D.42 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 6.

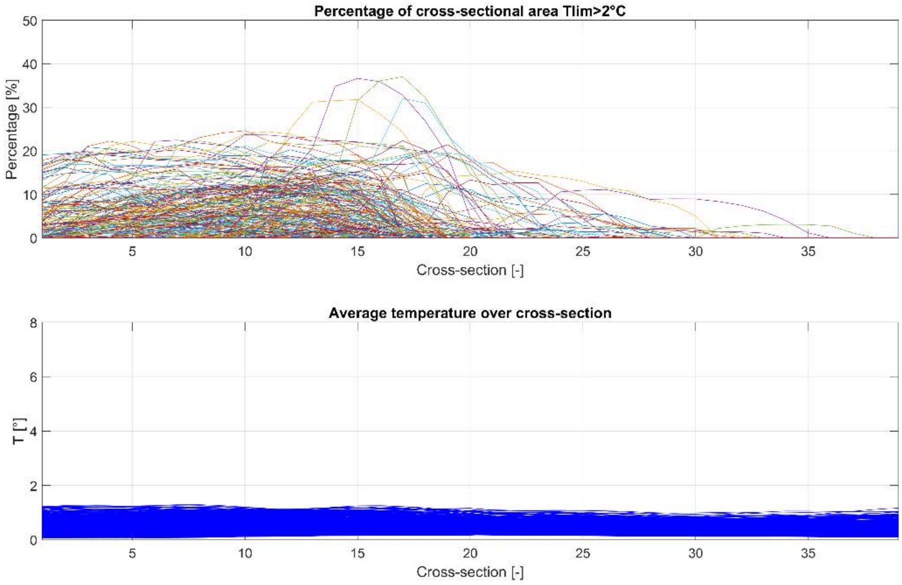

Figure D.43 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 7.

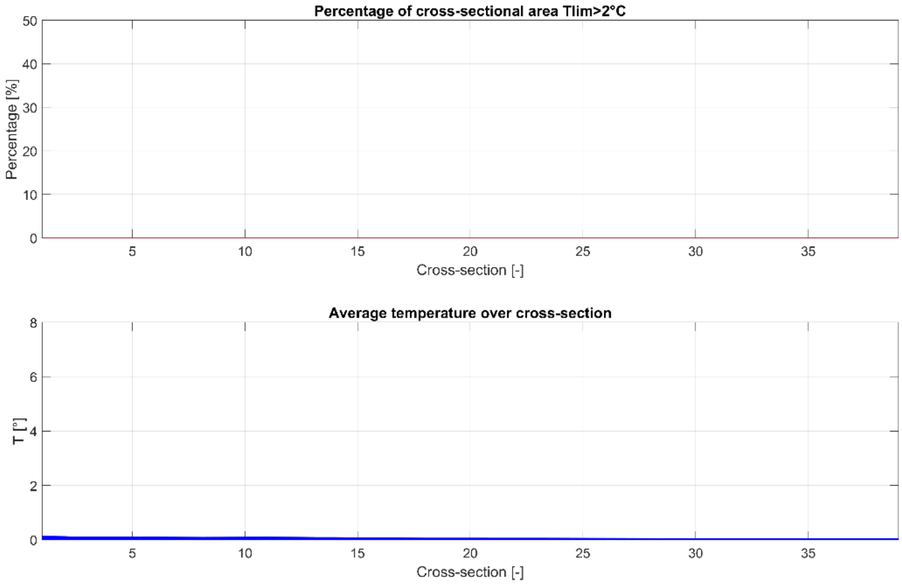

Figure D.44 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 8.

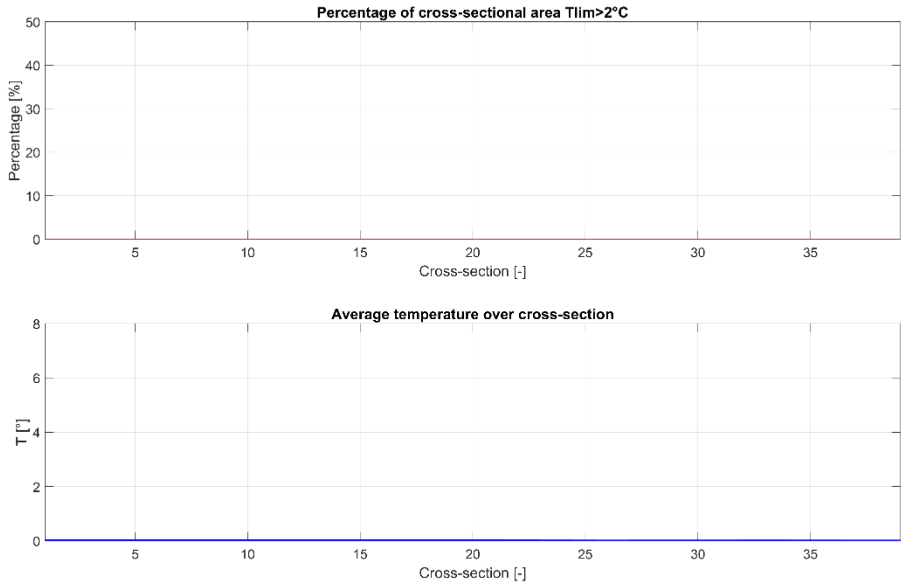

Figure D.45 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 9.

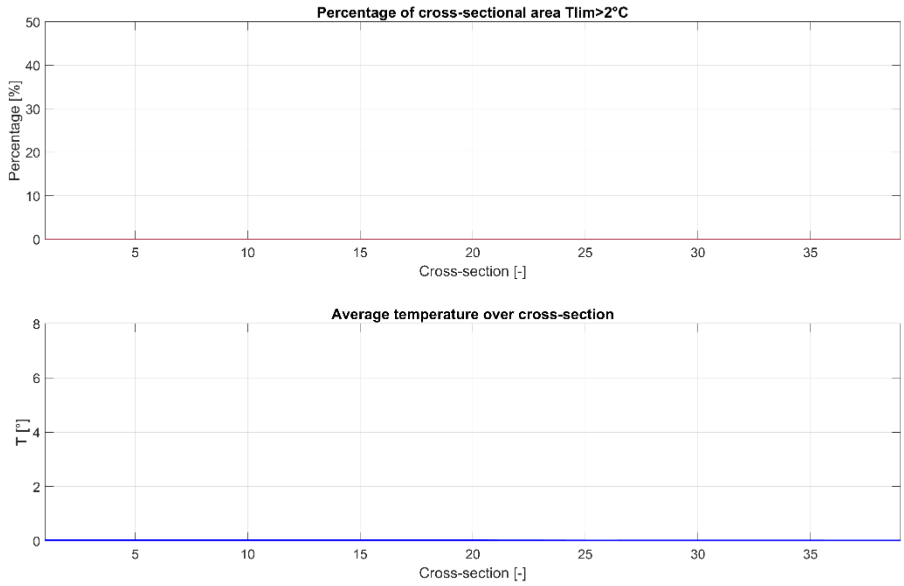

Figure D.46 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 9b.

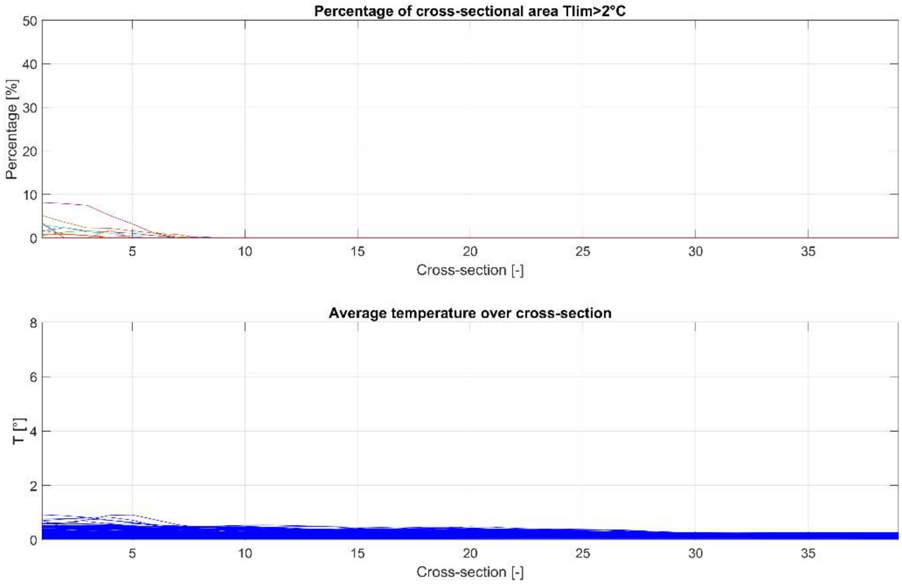

Figure D.47 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 10.

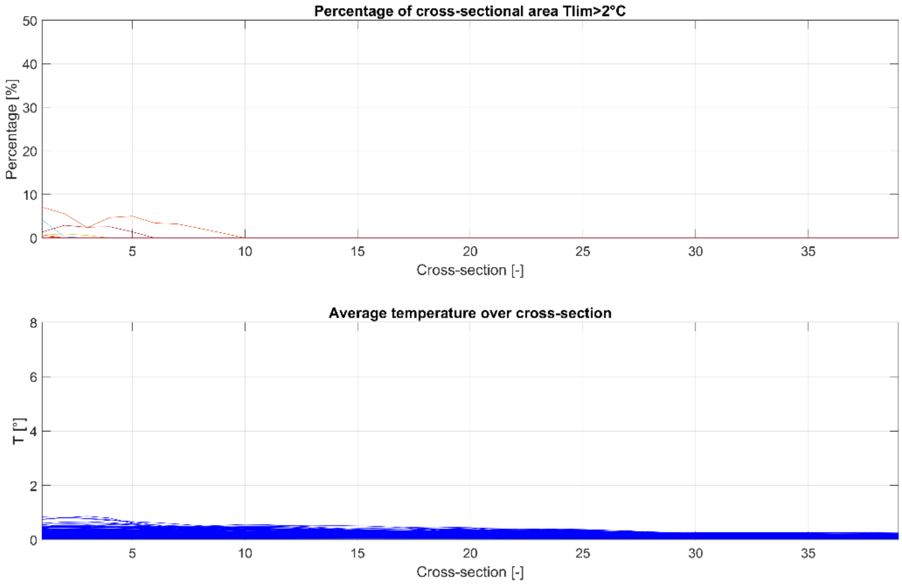

Figure D.48 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 11.

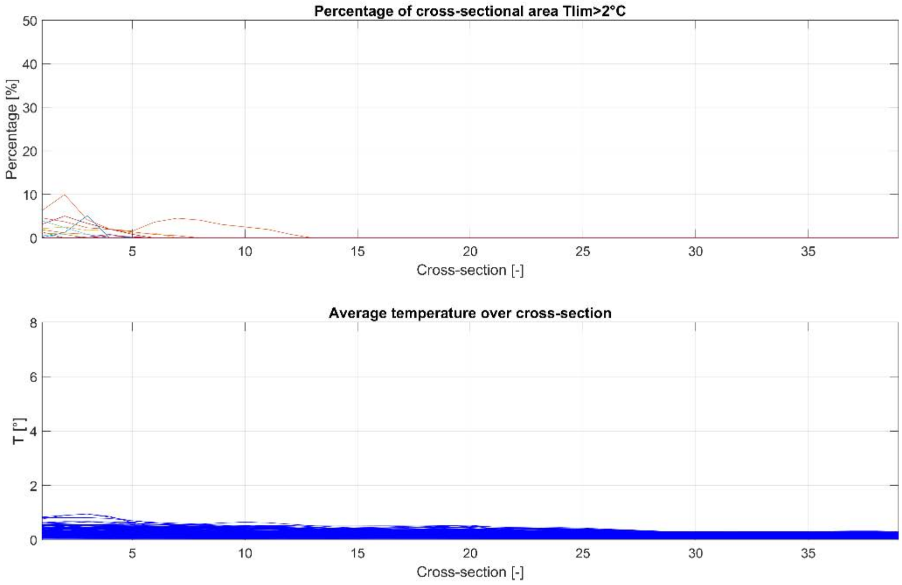

Figure D.49 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 12.

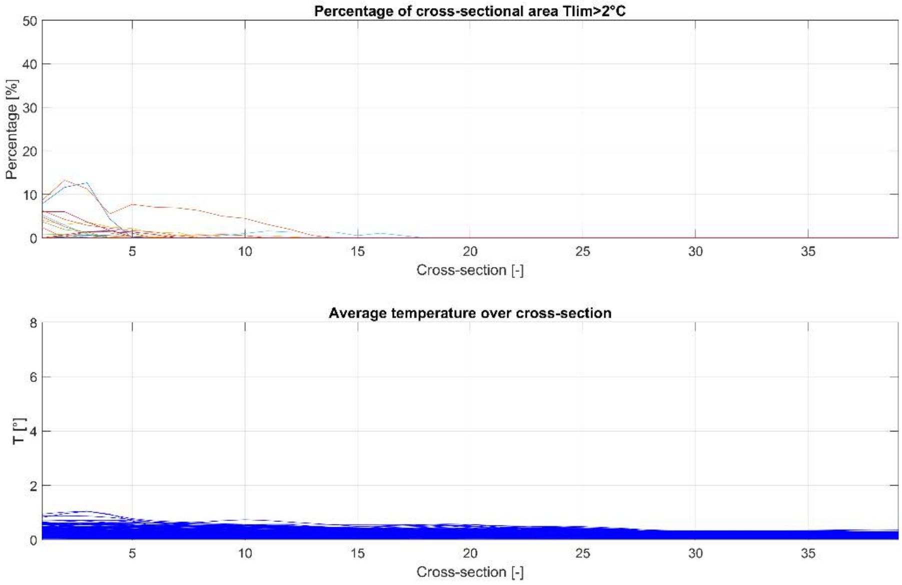

Figure D.50 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 13.

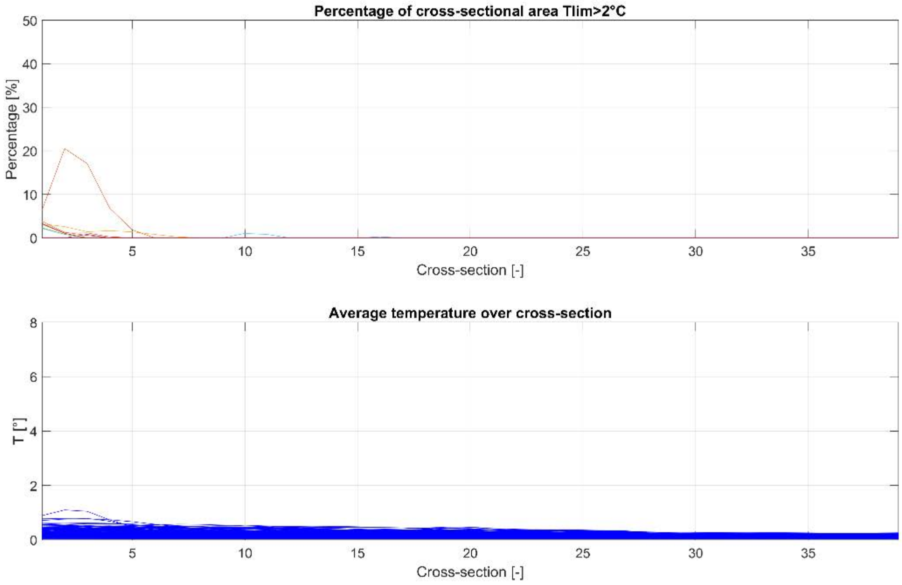

Figure D.51 Simulated percentage of the cross-sectional area covered by the mixing zone (top) and the average temperature increase over the cross-section (bottom) for the Cross-sections 2 area (Maasmond area towards the Calandkanaal area) - Case 14.

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